STEAMBOATS.

May 18, 1832.

Printed by order of the House of Representatives.

Mr. Wickliffe, from the Select Committee to which the subject had been referred, made the following

REPORT:

The Select Committee to whom was referred the report of the Secretary of the Treasury, and the documents accompanying the same, upon the subject of the explosions of boilers in boats propelled by steam, have had the same under consideration, and devoted as much of their time to its investigation as was compatible with the discharge of their other duties as members of this House.

The distressing calamities which have resulted from the explosion and collapsion of the boilers of steamboats, the increasing dangers to which the lives and property of so many of our fellow-citizens are daily and hourly exposed from this cause, unite in their demands upon that Government, possessing the competent power and authority, to throw around the lives and fortunes of those thus exposed, all the safeguards which a wise and prudent legislation can give.

The committee have had more difficulty in determining the extent of the power of Congress to legislate over the subject, than to decide what would be the proper legislation by a sovereign possessing unlimited and unrestricted powers over persons and things.

Whatever power of legislation over this subject is vested in Congress, refers itself to the 3d section of the 1st article of the constitution of the United States, which declares "that Congress shall have power to regulate commerce with foreign nations, and among the several States, and with the Indian tribes."

Under this power to regulate commerce among the several States, the right of Congress to prescribe the mode, manner, or form of construction of the vehicles of conveyance to be used for the transportation of commodities, is not perceived or recognized by the committee.

Whether the boat or vessel shall be propelled by the wind, or by paddles, or by steam, and, if by steam, whether it shall be a high or low pressure engine, &c., are questions with which it is believed Congress have nothing to do; and if the power were given by the constitution, its exercise might be of a doubtful expediency.

It is better to leave the subject of the application of steam power to the propelling of boats, to the sound discretion of those concerned, and to the improvements of the age, than to attempt, by any legislation of ours, to prescribe the particular kind of machinery to be employed.

If the suggestions of some, whose communications have been referred to the committee, were adopted, and Congress should undertake to prescribe, by legislation, the particular description of steam engines, their shape, construction, or model to be employed on board of steam vessels, it would be extremely difficult for Congress to keep pace in its legislation with the rapid march of improvement upon the subject of the application of steam power to machinery. Our legislation would lag behind the efforts of science and practical improvement. That which this Congress would adopt as the best and most expedient to be enforced by its legislation, would, perhaps, be condemned upon actual experiment or trial.

The committee have made these general remarks in answer to the varied and numerous recommendations contained in the mass of documents which accompany the report of the Secretary of the Treasury, that Congress should prescribe and adopt some general or uniform rule by which the machinery of steamboats shall be constructed, in whole or in part.

Many of these communications contain matter of interest, and are worthy to be communicated to the public, from which much scientific and practical information may be derived by those engaged in constructing and navigating steamboats. A selection of such, as, in the judgment of the committee, would be of advantage to the public, has been made, and are appended to this report. The committee submit them, without the expression of any opinion of their own, to the judgment of those whose intelligence and experience will enable them to determine correctly upon their respective merits.

An inquiry into the causes which produce the explosion of steam boilers, has engaged, for a series of years, the labors of many able and scientific men. The committee do not propose to pursue this subject by obtruding any opinions or speculations of their own. They will content themselves by stating, in brief, all the causes to which this effect of steam has been ascribed by the practical and scientific investigators.

1st. The faulty construction of boilers.

2d. The defective material of which they have been composed.

3d. Long use, by which the original strength of boilers has been weakened, and thereby rendered incapable of sustaining that pressure of steam for which they were originally constructed.

4th. Carelessness and want of skill in the engineers.

5th. An undue pressure of steam beyond the capacity of the strength of the boiler, no matter how perfect its construction or sound its material originally may have been.

6th. From a deficiency in the supply of water, producing an overheated steam, and increasing the heat of the flues of the boiler, which, when brought into sudden contact with water, through the agency of the supply pump, in increased quantities, produces a quality in steam which often causes explosions the most dangerous and disastrous.

No legislation is competent to annihilate those causes, or to prescribe and enforce the means of preventing their operation in all cases. Steam, and the mode of its application to machinery, is an agent which must be left to the control of intellect and practical science. It only belongs to legislation to excite, by rewards and punishments, that faithful application of those engaged in its use, which will best guard against the dangers incident to negligence.

The melancholy incidents which have occurred by the explosion of many

of the boilers of steamboats in the waters of the United States; the shock which is universally felt on these occasions, had impressed the committee with an opinion that the destruction of human life had been much greater than it turns out to be upon further and more minute investigation.

The whole number of explosions in the United States are ascertained to be fifty-two; number of killed, 256; and number of wounded, 104.

The committee propose to provide, by legislation, some safeguard against explosions produced by the 1st, 2d, 3d, and 6th causes stated above. Against the 4th and 5th causes, viz., carelessness and want of skill in the engineer; and an undue pressure of steam upon the boiler beyond its capacity, no adequate remedy, through or by the legislation of Congress, can be afforded. The remedy for this evil, if it belongs to legislation at all, must be furnished by the legislation of the several States. It would, in the opinion of the committee, be wiser, however, to leave it to be supplied by the interest and discreet judgment of the owners and masters of steamboats, which will always dictate the employment of those best skilled as engineers; whose characters would compel them to the performance of their duties as such, in a manner most advantageous to their employers, and most reputable to themselves.

Explosions which take place from the 1st, 2d, or 3d causes, enumerated above, may be truly said to be beyond the preventive power or control of the engineer. He cannot tell, when called to the management of an engine on board of a steamboat, that there has been a fault in the construction of the boilers—a defect in the material out of which they are composed—or that, by its too long use, the original strength has been so far impaired as not to be capable of sustaining the ordinary pressure of steam which belongs to the capacity of the boiler. He may not know how long the boilers or boat have been in use; consequently, no skill of his, thus situated, is, or can be, competent to guard against explosions produced by any or all of these causes.

The committee propose to furnish him and the community the means, by legislative enactments, of testing the strength of boilers, ascertaining their age, and determining whether the boat is fit for navigation.

It is proposed that there shall be appointed by the President of the United States, or by the Secretary of the Treasury, at suitable and convenient points upon the navigable rivers, and bays, and lakes of the United States, competent persons, whose duty it shall be to inspect the boats and boilers thereof, and test the strength of the boilers by hydraulic pressure. To require this to be done at least once in every three months, as a condition upon which a registry shall be made, or license granted, to a steamboat or vessel under the laws of the United States.

In this way, it is believed, these hidden and secret defects in boilers—injuries arising by incrustations in their bottoms, and the effects of use and time—can and will be detected.

It has been ascertained in the west, that a steamboat, after six or seven years' use, is unfit for safe navigation.

The many trials and tests to which the metal and strength of a boiler is exposed every year of this six or seven, must reduce its original strength and capacity for resisting the power of steam.

So far as the committee are informed, there exists, at this time, no system or practice in any portion of the Union, by which the strength of a steam boiler is tried after it has passed the first ordeal in the hands of the original maker; and, generally, the first evidence which is afforded of its un-

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fitness for use, is by its explosion, thereby destroying the lives and fortunes of many of our wealthy and enterprising citizens.

It is when one or more of these causes exist, and exert a separate or combined influence, that explosions have taken place, when there was no deficit of water in the boiler, and no unusual pressure of steam upon the engine; and, in many cases, when the pressure of steam at the time was less than had ordinarily been given. Without an inspection and trial of strength in some such mode as that herein indicated, how is it possible to guard against, or prevent explosions, by any skill or vigilance on the part of the engineer? All the plans of safety-valves, and improvements recommended in their construction or management, cannot, will not, prevent explosions from one or all of the three first causes stated. They may appear plausible in theory, but would be unavailing in practice.

Those explosions, produced by the sixth cause, viz. a defect of water in the boilers, &c. may, more or less, if not altogether, be guarded against by the vigilance and skill of the engineer, when the engine is properly constructed, so that the force pump shall be competent, by its action, to supply the water as fast as it may be converted into steam. Sometimes the functions of this pump are suspended by accident, at others, by design on the part of the engineer. If by accident, then the skill of the engineer may be competent to detect and avert the evil.

It often happens, when a steamboat is stopped to take in, or let out passengers or loading, when detained for the purpose of "wooding," that the engineer neglects or fails to ungeer his wheels or paddles, and keep his engine in motion, by which the steam would be worked off regularly, and the boiler supplied with water, he trusts too long and too fatally to his safety-valve and the strength of the boiler. The fires are kept up, the water is converted into steam that becomes heated, the water sinks below the flues, which becomes heated to excess; and when the engine is started, the water is thrown into the boilers in an increased quantity, which, coming in contact with the flues heated to a rend heat, is instantly converted into a steam in greater quantities than can be worked off by the engine, or escape through the safety-valve. Thus it is, almost all of the explosions which have taken place from this cause have occurred while the boat was stationary, or immediately after getting under way.

To guard against accidents of this description, the committee propose to make it the duty, under a heavy penalty, of a master of a boat and the engineer, whenever his boat is stationary; for any cause, to ungeer the weecls, keep the engine in motion, supply the boilers with water, and work off the steam.

Neither of these regulations can prove burthensome or inconvenient to the navigation of steamboats. It is believed they will furnish some security to the lives of passengers. To obviate all possible objection to the first regulation proposed, upon the score of expense, and as an inducement to a compliance with the requirements proposed by the bill, the expense of making the inspection of the boat, and of testing the valve as proposed, the bill provides that the cost shall be paid by the United States.

The time necessary to make the inspection and trial cannot exceed six hours in every six months. The apprehension of having their boilers condemned, will excite men to vigilance and care on the part of their masters and engineers. They will be induced more frequently to remove the in-

crustations of salt or lime, which are constantly forming in the boilers, and, in progress of time will, more or less, affect their strength.

In connection with this subject, the committee have been induced to consider and inquire into other causes of danger to the lives and property on board of steamboats, and have ventured to propose, for the consideration of the House, the possible means of preventing them; at least, of mitigating the extent of the evil consequences incident to them. The first to which your committee will advert, is the destruction of steamboats by fire. Three cases of this description have recently occurred, one in the waters of New York, and two on the Mississippi and Ohio rivers. On board of one of the boats recently destroyed on the Ohio river, there were 174 passengers, 100 of whom were burned to death or drowned in attempting to escape from the flames. When a steamboat takes fire in the upper deck or cabin, the flames spread with such rapidity, it often happens that she is consumed before she reaches the shore.

Every boat should be provided with a competent number of long boats and yawls, to enable the passengers to seek safety in flight in case of fire or sudden destruction by sinking. Such was not the case in the instance alluded to, and in other cases of a similar kind, when the passengers have been compelled to choose between the dread alternatives of either remaining on the boat, and be consumed by fire, or jumping into the river, and be drowned.

Every steamboat, before she is licensed or registered, the owner or master should be required to provide, as a part of her furniture, a suitable fire engine and hose, also a competent number of long boats or yawls, to be regulated in proportion to her tonnage, and the should be bound to carry the same, in good order, upon every voyage. The additional expense would be trifling. With the aid of a fire engine, it is believed that the fire of any steamboat, taken in time, might be extinguished, certainly checked, so far as to enable the passengers to escape.

The next cause of danger, to which your committee would invite the attention of the House, and invoke for it, as for the others, its legislative interposition, is, that of steamboats, moving in opposite directions in the night, coming in contact. This often happens when both are using every exertion to avoid such contact.

It is often impossible for the pilot of one boat to tell the direction of the other; and frequently, at the moment when least expected, they come in contact, producing disasters most fatal to the lives of passengers on board. This difficulty has been felt on the rivers of the west, and injuries to such an extent sustained, that some regulation by Congress is imperiously demanded.

Upon advising with a gentlemen whose experience entitles him to great consideration, he recommended that it should be made the duty of the commandant of the boat descending the river, to shut off his steam, and permit his boat to float with the current, whenever the two boats came within one-half mile of each other; the ascending boat would then assume the responsibility of steering clear of the descending boat. The master or pilot on board the ascending boat, in that event, would labor under no mistake as to the particular direction of the one descending, as he must know that her direction was regulated by the current of the stream. This regulation, it is true, would not apply to boats navigating the bays, lakes, and tide-water rivers of the United States; but it is equally true that, in these waters, such regulation is not so much required, because of the greater width and

depth of channel: it is otherwise in the rivers, and particularly in the rivers of the west, where the channels are narrow, and in places very shoal.

To guard against accidents on tide-waters, the bill makes it the duty of the master and owner of the boat to keep suspended, in the bow and stern of his boat, a light at least three feet above the deck of his vessel, whenever the same shall be navigated at night.

If it be asked of the committee whence is the power of Congress derived to enact these regulations, and impose these conditions upon the navigators of steam vessels? they respond to the inquiry, by referring to the same general grant of power under which Congress has undertaken to regulate navigation, and to prescribe the duties and responsibilities of masters of ships and vessels at sea, or engaged in the coasting trade.

If Congress possess the power to compel the master or owner of a vessel sailing from the United States to a foreign port or country, to provide for the use and benefit of his crew a medical chest, or to prescribe the quantity and kind of provisions and water he shall take on board, (and surely no one will be found, at this day, to question this power so long exercised by the Congress of the United States,) then it is respectfully contended by the committee, that the like power exists, and should be exerted, to enact and enforce all the regulations which they have recommended and embodied in the bill reported. If Congress have power to require the captain of a ship to provide his crew with the means of preserving health on board, the like power exist to compel the masters and owners of steamboats engaged in carrying on the internal commerce "among the several States," to provide the means of preserving the lives of those on board from danger of steam, of fire, or of water.

The conditions which the committee propose to add to those already imposed on the fulfilment of which steam vessels are enrolled and obtain licenses to navigate the waters of the United States, are not burthensome or inconvenient: they are reasonable and proper, and, if enforced, will give additional security to the lives and property of the most enterprising citizens.

The committee, therefore, report a bill, and earnestly entreat the House to give to it that consideration which the nature and importance of the subject demand; and, if the same shall be approved, that the House will pass upon it at the present session, and, as far as possible, give quiet and repose to the public mind, which has been so long and so anxiously directed to this subject.

A BILL

To provide for the better security of the lives of Passengers on board of vessels propelled in whole or in part by steam.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That it shall be the duty of all owners of steamboats, or vessels propelled in whole or in part by steam, on or before the first day of October, one thousand eight hundred and thirty-two, to make a new enrolment of the same under the existing laws of the United States, and take out from the collector or surveyor of

the port, as the case may be, where such vessel is enrolled, a new license, under such conditions as are now imposed by law, and as shall be imposed by this act.

Sec. 2. *And be it further enacted,* That it shall not be lawful for the owner, master, or captain of any steamboat, or vessel propelled in whole or in part by steam, to transport any goods, wares, and merchandise, or passengers, in or upon the bays, lakes, rivers, or other navigable waters of the United States, from and after the said first day of October, one thousand eight hundred and thirty-two, without having first obtained from the proper officer a license under the existing laws, and without having complied with the conditions imposed by this act; and for each and every violation of this section, the owner or owners of said vessel shall forfeit and pay to the United States the sum of five hundred dollars, one-half for the use of the informer; and for which sum or sums the steamboat or vessel so engaged shall be liable, and may be seized and proceeded in against summarily, by way of libel, in any district court of the United States having jurisdiction of the offence.

Sec. 3. *And be it further enacted,* That it shall be the duty of the President to appoint, at such ports on the navigable waters, bays, lakes, and rivers of the United States, as in his judgment will be most convenient to the owners and masters of steamboats and vessels propelled in whole or in part by steam, one or more persons skilled or competent to make inspections of such boats and vessels, and of the boilers and machinery employed in the same, whose duty it shall be to make such inspection when called upon for that purpose, and to give to the owner or master of such boat or vessel duplicate certificates of such inspection.

Sec. 4. *And be it further enacted,* That the person who shall be called upon to inspect the hull of any steamboat or vessel under the provisions of this act, shall, after a thorough examination of the same, give to the owner or master, as the case may be, a certificate, in which shall be stated the age of said boat or vessel, when and where originally built, and the length of time the same has been running. And he shall also state whether, in his opinion, the said boat or vessel is sound and fit to be used for the transportation of freight or passengers; for which service so performed on every boat or vessel, the inspector shall be paid and allowed by the Secretary of the Treasury, the sum of ——— dollars.

Sec. 5. *And be it further enacted,* That it shall be the duty of the person or persons who shall be called upon to inspect the boilers and machinery, under the third section of this act, fully and thoroughly to inspect and examine the engine and machinery of said boat, and state his opinion of its soundness; and he shall, moreover, provide himself with a suitable hydraulic pump, and, after examining into the state and condition of the boiler or boilers of such boat or vessel, it shall be his duty to test the strength and soundness of said boilers by applying to the same an "hydraulic pressure, equal to three times the pressure that the boilers are allowed to carry in steam;" and if he shall be of opinion, after such examination and test, that the said machinery and boiler are sound and fit for use, he shall deliver to the owner or master of such vessel or boat duplicate certificates to that effect, stating therein the age of the said boilers; one of which it shall be the duty of the said master and owner to deliver to the collector or surveyor of the port wherever he shall apply for license, or for a renewal of a license, the other he shall cause to be posted up, and kept in some conspicuous part of the said boat for the information of the public; and for each and every in-

spection and test of the boiler so made, the inspector shall be paid, by the Secretary of the Treasury, the sum of ten dollars.

SEC. 6. *And be it further enacted,* That it shall be the duty of the owners and masters of steamboats to cause the inspection, provided under the fourth section of this act, to be made at least once in every twelve months; and the examination and trial of the strength of the boilers of his boat, required by the fifth section, at least once in every three months, and deliver to the collector or surveyor of the port where his boat or vessel has been enrolled or licensed, the certificate of such inspection; and on a failure thereof, he or they shall forfeit the license granted to such boat or vessel, and be subject to the same penalty as though he had run said boat or vessel without having obtained such license, to be recovered in like manner.

SEC. 7. *And be it further enacted,* That whenever the master of any boat or vessel, or the person or persons charged with the navigating said boat or vessel, which is propelled in whole or in part by steam, shall stop the motion or headway of said boat or vessel, or when the said boat or vessel shall be stopped for the purpose of discharging or taking in cargo or passengers, or when "wooding," and the steam in said boiler shall be equal to one ———, the ascertained strength of said boiler, he or they shall keep the engine of said boat or vessel in motion sufficient to work the pump, give the necessary supply of water, and to keep the steam down in said boiler to what it is when the said boat is under headway, at the same time lessening the weight upon the safety-valve, so that it shall give way when the steam in said boiler is equal to one ——— of its ascertained strength, under the penalty of two hundred dollars for each and every offence.

SEC. 8. *And be it further enacted,* That the penalties imposed by this act may be sued for, and recovered in the name of the United States, in the district court of such district or circuit where the offence shall have been committed or the forfeiture incurred, one half to the use of the informer, and the other to the use of the United States.

SEC. 9. *And be it further enacted,* That it shall be the duty of the owner and master of every steam vessel engaged in the transportation of freight or passengers, to provide, and to carry with the said boat or vessel upon each and every voyage, one long boat or yawl for each fifty tons of said boat or vessel, which long-boat or yawl shall be competent to carry at least twelve persons; and for every failure in this particular, the said master and owner shall forfeit and pay three hundred dollars.

SEC. 10. *And be it further enacted,* That it shall be the duty of the master and owner of every steam vessel to provide, as a part of the necessary furniture, a suction hose, and fire engine and hose, suitable to be worked on said boat in case of fire, and carry the same upon each and every voyage in good order, and for a failure to do which they, and each of them, shall forfeit and pay the sum of three hundred dollars.

SEC. 11. *And be it further enacted,* That it shall be the duty of a master and pilot of a steamboat, except those navigating tide water, when descending any river or stream in the night, where the descending boat shall come within one half mile of an ascending steamboat, to shut off steam, and permit his boat to float upon the current of the river until the ascending boat shall have passed, and the master and owner of the ascending boat shall then assume the responsibility of steering clear of the descending boat, and be liable, in damages, to the extent of the injury which may be sustained.

Sec. 12. *And be it further enacted,* That it shall be the duty of the master and owner of every steamboat, running in the night, tosuspend two lights, (at least three feet above the deck of his boat,) the one at the bow and the other at the stern, under the penalty of two hundred dollars.

No. 1.

Treasury Department, *March* 2, 1832.

Sir: In compliance with a resolution of the House of Representatives of the 19th of December, 1831, directing the Secretary of the Treasury "to communicate to the House such information as the department may have collected upon the subject of steamboat navigation, with a view to the adoption of such measures as may be deemed practicable the better to guard and protect passengers from the danger of the bursting of boilers;" I have the honor to transmit—1st. Returns received from the several collectors, marked A, and numbered from 1 to 58, inclusive. 2d. Various communications in answer to "interrogatories in relation to the bursting of steam boilers," which are marked B, and numbered from 1 to 31, inclusive. 3d. Translations of circulars, marked C, and numbered 1 and 2, from the Director General of roads, bridges, and mines, in France, to the Prefects of the departments; being all the information in possession of the department.

In order to be the better enabled to comply with that part of the resolution of the House of Representatives of May 4, 1830, which directs the Secretary of the Treasury to report to the House his views on the information that resolution requires him to collect, it was the intention of the department to have placed all the papers, preparatory to submitting them to the House, in the hands of one or more gentlemen, competent, from their knowledge of the subject, to pronounce upon the practical value of the facts and suggestions they present, with the hope that, by the aid of the information contained in them, and that which the person selected might add from his own and other sources, some scheme of measures might be suggested for promoting the object for which the inquiry was instituted by the House; and, if such should be the pleasure of the House, the papers can be returned to the department, and this intention carried into effect.

The experiments of the "Franklin Institute," of Philadelphia, undertaken with a view to ascertain the causes of the explosion of steam boilers, are yet in progress, and the result, when received, will be communicated.

For a knowledge of the steps taken by my predecessor to collect information upon this subject, I beg leave to refer to a report of the Secretary of the Treasury, of the 3d of March, 1831.

Finding that facts sufficient for a compliance with the resolution of May 4, 1830, had not been received, soon after I entered upon the duties of the department, further measures were taken to obtain them, by publishing a notice in various newspapers throughout the United States, and issuing the circular to collectors, of 31st October, 1831, copies whereof, marked D and E, are herewith transmitted. Most of the papers, marked B, have since

been received; and, although they continue to arrive, it is not thought expedient further to defer this report.

I am, respectfully, your obedient servant,

LOUIS McLANE,
Secretary of the Treasury.

To the hon. the SPEAKER
of the House of Representatives.

No. 2.

Circular to Collectors.

TREASURY DEPARTMENT, *October* 31, 1831.

SIR: The House of Representatives, by a resolution of the 4th of May, 1830, directed the Secretary of the Treasury to collect and communicate to the House such information, and report his views on the same, as in his opinion may be useful and important to Congress in enacting regulations for the navigation of steamboats or steam vessels, with a view to guard against the dangers arising from the bursting of their boilers.

Among the means of obtaining the information necessary to a compliance with the resolution, it has been deemed proper to obtain, through the aid of the collectors, an account of the engines now used on board the steamboats in their respective districts. A form has accordingly been prepared, and is now transmitted to you, to be filled up with the particulars indicated in the several columns. Any other facts which may be considered pertinent to the inquiry, may be inserted under the head of remarks.

To obtain the information required, you are requested to address yourself to the owner of each steamboat in your district; and it is hoped that, in consideration of the benevolent and important object of the resolution, the co-operation of those gentlemen will be cheerfully and promptly afforded.

Your returns should be made as early as may be in the month of December.

I enclose for your information a copy of a notice on the subject, which has been published in all the papers authorized to publish the laws.

I am, sir, very respectfully, your obedient servant,

LOUIS McLANE,
Sec'y of the Treasury.

Interrogatories in relation to the bursting of Steam Boilers.

1. Are you acquainted with the use and nature of steam engines? In what employment have you been engaged? Were you present, and in what capacity, at the bursting of any steam boiler, or collapsing of a flue? or have you been made acquainted, by other means, with the facts in any such case? If so, in what case?

2. In that case, was the water in the boiler between the gauge cocks? If not, at what height compared with the lower gauge cock?

3. If the boiler contained a flue, what was the difference between the height of its upper side and that of the lower gauge cock?

4. What was the weight per square inch on the safety-valve?

5. Had the safety-valve ever been found rusted or sticking in the aperture, or was it so at the time?

6. Had that part of the boiler above the water ever been heated to a red heat, or approaching thereto?

7. Was there any incrustation or sediment found at the bottom of the boiler? If so, what was its thickness and composition?

8. In what part was the boiler rent, and what was the appearance and extent of the rent?

9. If the bursting happened to the boiler of a steamboat, was the boat under way or at rest? Was the valve open? If so, how long before the accident? Was it opened by the engineer or by pressure?

10. Was the piston going at its usual speed, or faster, or slower?

11. Had the firemen found any unusual difficulty in keeping up the motion of the engine previously to the bursting of the boiler; and, if so, how long before?

12. Do the iron boilers used in the western waters generally accumulate a calcareous incrustation at the bottom? If so, have any or what means been used, with success, to prevent it?

13. Is it observed, that, when there is a sediment or incrustation on the bottom of the boiler, it requires more fire than usual to raise the steam? and how often is the sediment removed, and by what means?

14. Are any means used for preventing incrustation on the bottom of boilers? and, if so, what effect has been observed?

15. Have any means been employed to prove steam boilers before they are used or afterwards, and what pressure has usually been applied to iron of a given thickness? Are the proofs made when the iron is cold or hot?

16. Is there any instrument employed to ascertain the temperature of the boiler above the water, or of the steam in the upper part of the boiler? If so, what is it?

17. What means are used to prevent the fire from the fire place and flue from extending to the boat?

18. Have you ever seen steam boilers heated to a red heat on the upper side? If so, is such a temperature regarded as a cause of exploding the boiler?

19. Have any means been used in the construction of boilers or fire places to prevent the heating of the upper part of the boiler? If so, what are they?

20. How many persons were scalded by steam, and at what distance was each from the boiler? At what distance from the boiler was the steam supposed to be hot enough to scald? Was the current of steam from the rent in the boiler instantaneous, or did it continue for some time, and how long? What number of persons were wounded by the parts of the boiler or machinery which were driven off by the explosion, and what position did each of such persons occupy in the boat?

21. Have you ever observed the piston to move irregularly for a few minutes, or for a few strokes, alternately faster or slower than its usual speed, without perceiving any change in the resistance to the paddles, or any other obvious cause for such irregularity? and, if so, how was it accounted for?

22. To what immediate cause have you attributed the bursting of the steam boilers which have come within your knowledge?

23. Are there any other facts within your knowledge, in relation to this subject, which appears to be important in the present inquiry? If so, please to state them?

24. If present at the bursting of a steam boiler, did you observe any interval of time between the first indication of the boiler giving way and the general explosion?

No. 3.

Answers to interrogations on the bursting of Steam Boilers, with remarks thereon, by William C. Redfield, of New York.

NEW YORK, *December* 23, 1831.

SIR: In compliance with the request contained in the circular from the Treasury Department, the undersigned respectfully offers to the consideration of the honorable Secretary, and of Congress, the following facts and observations in relation to the explosion of steam boilers, and the means of guarding against such accidents. In performing this duty, I shall first attempt to answer some of the queries put forth by the department, in their order.

1. Are you acquainted with the nature and use of steam engines? In what employment have you been engaged? Were you present, and in what capacity, at the bursting of any steam boiler or collapsing of a flue? or have you been made acquainted, by other means, with the facts in any such case? If so, in what case?

To the points embraced in this interrogatory, the undersigned answers, that he has been long acquainted with the nature and principles of the steam engine, and, for the last ten years, has been chiefly engaged in the construction and management of steamboats, in which have been used engines of various descriptions, from ultra high pressure to ordinary low pressure, with various intermediate modifications of the two principles. He has not been actually present at the bursting or disruption of any boiler, nor has any boiler been exploded under his care, but has had opportunities for examining the effects of heat upon portions of a boiler not covered by water; and, furthermore, has made a strict professional examination of all the boilers which have failed, under the pressure of steam, in this part of the United States, so far as he could obtain access to them, and has availed himself of such other evidence, in relation to these cases, as he was able to obtain. The cases so examined may be enumerated as follows: 1st, Etna; 2d, Jersey; 3d, Patent; 4th, Bellona; 5th, Fidelity; 6th, Legislator; 7th, Constitution; 8th, Hudson; 9th, Franklin; 10th, Oliver Ellsworth; 11th, Carolina; 12th, C. Justice Marshall, 13th, United States; 14th, General Jackson.

2. In that case, was the water in the boiler above the guage cocks? If not, at what height compared with the lower guage cock?

In all of these cases, except the first, and *possibly* two or three others at the head of the list, I am convinced that the boilers had a competent supply of water previous to, and at the time of, the accident. As this opinion is contrary to the current views which prevail in relation to these cases, it is proper to state some of the evidence on which it is founded.

1st. The state and appearance of the metal after the explosion in those parts of the boiler most exposed to a deficiency of water and to the action of fire, has indicated no such exposure to heat. This species of evidence is far more to be relied on than the current opinions of engineers or others on this subject. In all cases in which boilers have been so exposed, which have came under my notice, the metal has shown striking and infallible indications of such neglect in being discolored and oxydated, and in having its surface unequally depressed by the pressure of the steam acting upon the metal when the latter is raised to a red heat. Not the remotest evidence of such exposure has been discerned by me in the cases above specified.

2d. With the exceptions above named, the disruption *has not commenced in those parts of the boiler which are most exposed by a deficiency in the supply of water*, but has most often commenced in the sides or bottoms of large or otherwise ill constructed flues, while the parts of the boiler most exposed to the action of the fire received no injury. In one case where the failure took place in the top of a large and unsupported flue, it originated in the separation or fracture of a joint in the line of rivits, about ten feet from the furnace.

3d. The direct testimony of those who have been most immediately engaged in the care of boilers and engine at the time of these accidents.

This evidence has been, not only particular and distinct in its details, but, in some cases, has been of the most disinterested and solemn character.

3. If the boiler contained a flue, what was the difference between the height of its upper side, and that of the lower guage cock?

All the boilers included in the above cases contained flues, except those of the Etna. In this last case, I understood there was an acknowledged deficiency of water, occasioned, as is said, by the encrustation and obstruction of a very small supply pipe. In the other cases, there was various differences between the height of the upper side of the flues and that of the lower guage cock, averaging, probably, 12 inches.

4. What was the weight per square inch on the safety-valve?

The Etna was propelled by a high pressure engine, usually carrying (as was said) 150 pounds to the square inch, and, immediately previous to the disaster, was stated to have been running slower than usual, indicating less pressure, but, *probably*, with a red hot boiler. The other boats named above *were all low pressure*, and carried from seven to seventeen or twenty pounds pressure to the square inch.

5. Had the safety-valve ever been found rusted or sticking in the aperture, or was it so at the time?

The care taken in the construction of safety-valves, and the frequent lifting or use which is made of them by the engineers, generally prevents such adhesion. Several of the boats specified were blowing off steam at the moment of the accident, *and all*, except the Etna, *were furnished with mercurial guages, indicating the exact pressure, and which would have discharged the mercury, and have blown of steam, had the usual pressure been much increased.*

6. Had that part of the boiler above the water ever been heated to a red heat, or approaching thereto?

As regards the above boilers, I am not informed on this point. Of boilers carried at *former periods* in some of these boats, I have known a few to become thus heated, which were afterwards subject to my inspection. As this event sometimes happens without occasioning any further accident, it *may* have occurred on board some of the other boats included in my list.

7. Was there any incrustation or sediment found at the bottom of the boiler? If so, what was its thickness and composition.

I have seen no evidence of incrustations, as connected with these accidents, but I have seen the usual deposite of sea water, connected at times with a stratum of salt, forming an incrustation from an eighth of an inch to one inch in thickness. This, however, was in cases where the boilers had been injured by heat, while deficient in water. I have, also, known the same evil to result from a neglect to change the water with suficient frequency in boats running on sea water routes.

8. In what part was the boiler rent, and what was the appearance and extent of the rent?

The boiler of the Etna (which was the central one of three, and in the form of a cylinder, of 30 inches diameter) was ruptured or torn across the bottom, the rent extending in a spiral direction more than once around the boiler. The general appearance of the metal in other boilers examined, has been already mentioned, and the extent of the rent and displacement of the parts has usually been such as seemed naturally to result from the giving way of the metal at a single point. The rupture would from thence be extended till the force or pressure ceased by being thus relieved, and those parts which were found at the greatest distance from their original position, I have assumed to be those which first gave way.

9. If the bursting happened to the boiler of a steamboat, was the boat under way, or at rest? Was the valve open? If so, how long before the accident? Was it opened by the Engineer or by the pressure?

In seven of the cases mentioned, the boats were under way, and had been so for a considerable period of time. In the seven other cases, the boats were either at rest or had but recently started their engines.

10. Was the piston going at its usual speed, or faster or slower?

Nothing remarkable on this point has been noticed, except in the case of the Etna, whose piston is said to have been moving with less than the usual speed immediately previous to the accident.

11. Had the firemen found any unusual difficulty in keeping up the motion of the engine previously to the bursting of the boiler? and, if so, how long before?

No particular difficulty of the kind referred to, is known to have existed, except it be in the case last mentioned.

12. Do the iron boilers used in the western waters generally accumulate a calcerous incrustation at the bottom? If so, have any or what means been used, with success, to prevent it?

This question appears to refer exclusively to boats in the western waters.

13. Is it observed that when there is a sediment or incrustation on the bottom of the boiler, it requires more fire than usual to raise the steam? and how often is the sediment removed, and by what means?

Such sediment necessarily lessens the quantity of steam generated by a given quantity of fuel. Most boats carry at all times a full fire, which is not likely to be increased from the cause mentioned. Sediment is best removed by frequent cleaning of the boilers, *and is best prevented by a frequent blowing off of surplus water from the end of the boiler opposite to that at which the water is received.*

14. Are any means used for preventing incrustations on the bottom of boilers? and, if so, what effect has been observed?

Answer comprised under the last head.

15. Have any means been employed to prove steam boilers before they are used and afterwards, and what pressure has usually been applied to iron of a given thickness? Are the proofs made when the iron is cold or hot?

The writer (and, to his knowledge, other managers of steamboats) has frequently tested the strength of boilers by a hydrostatic pressure applied by means of the forcing pump, with a heavy load on the safety-valve. The form and dimensions of the structure afford, however, a safe means of judging of its comparative strength. The thickness of the metal need not to be taken into the account in a comparative estimate of strength, as it is seldom varied to much extent or with much advantage. A fact with which practical men are familiar.

16. Is there any instrument employed to ascertain the temperature of the boiler above the water, or of the steam in the upper part of the boiler? If so, what is it?

Not often, and perhaps never; engineers would generally, I think, doubt of its utility.

17. What means are used to prevent the fire from the fire place and flue from extending to the boat?

In most of the cases now under notice, the fire has been entirely enclosed by the boiler. In other boats of more recent construction, floors of brick, and sheet iron at the bottom of the flues, and at a distance from the wood work, together with other preventives, have been used with success.

18. Have you ever seen steam boilers heated to a red heat on the upper side? If so, is such a temperature regarded as a cause of exploding the boiler?

Never saw or heard of a boiler so heated.

19. Have any means been used in the construction of boilers or fire places to prevent the heating of the upper part of the boiler? If so, what are they?

The only "upper part of the boiler" to which the fire can possibly have access, is of course, or should be, always covered with water. The most approved instruments or means for preventing accidents, and securing this supply, and the safest in common hands, are the mercurial guage, the try cocks, the glass eye guage, and good forcing pumps. Of the practical utility of floats, &c. in steamboat boilers, I am not satisfied.

20. How many persons were scalded by steam, and at what distance was each from the boiler? At what distance from the boiler was the steam supposed to be hot enough to scald? Was the current of steam from the rent in the boiler instantaneous? or did it continue for some time, and how long? What number of persons were wounded by the parts of the boiler or machinery which were driven off by the explosion? and what position did each of such persons occupy in the boat?

For a statement of the number injured by the accidents which I have specified, and in other cases, I beg leave to refer to a list published in the American Journal of Science and Arts, vol. xx, page 336, published in July, 1831, and to some remarks annexed thereto, which pertain to the subject; a copy of which paper, marked A, together with a short article on this subject, marked B, from vol. xxi, page 190, of the same Journal, is hereunto annexed. The fact is well known that steam of a low pressure and temperature will, either in volume or in jet, prove injurious at a far greater distance from the boiler than that of a high temperature and pressure. The duration of the current of steam from boilers which have been ruptured, has doubtless been controlled by the size of the opening through which it was discharged.

One of those discharges, which I witnessed at a short distance, was of considerable duration, being through a comparatively small opening. I know of no circumstances respecting the exposure of particular individuals, from which useful conclusions could be drawn.

21. Have you ever observed the piston to move irregularly for a few minutes, or for a few strokes, alternately faster or slower than its usual speed, without perceiving any change in the resistance to the paddles, or any other obvious cause for such irregularity? and, if so, how was it accounted for?

Such irregularities in the speed of the piston, always occur in navigating among eddies and counter currents, and in passing from deep to shallow water, and *vice versa*. I have no reason to suppose them to be neglected by engineers, in cases where the cause is not obvious.

22. To what immediate cause have you attributed the bursting of the steam boilers which have come within your knowledge.

In almost every one of the cases which I have brought under notice, excepting that of the Etna, I am fully satisfied, by my own investigations, that the immediate cause of the disaster is to be found in the faulty construction of the boilers which were formerly in use, and not to carelessness or inattention, in the proper sense, on the part of those to whose care they were entrusted. It is no sufficient answer to this view of the subject, to allege that the same boilers had long been used under the same, or nearly the same pressure, without accident. It is a fact well known, that carriages, bridges, forest trees, strings of musical instruments, and, also, various descriptions of machinery, often break under a strain not exceeding that to which they have been long accustomed, and sometimes under a force far below that which is usually endured.—The only matter of wonder in relation to many of these boilers, should be, that they held out so long under the pressure to which they were made subject. One probable, if not prominent, cause of this failure after long proof, will hereafter be alluded to.

23. Are there any other facts within your knowledge in relation to this subject, which appears to be important in the present inquiry? If so, please to state them?

In answer to the general inquiries here made, the undersigned will offer a few remarks: to attempt to elucidate the whole subject in a satisfactory manner, would seem to require an extensive and practical treatise on the art of steam navigation.

On the western waters of the United States, the exposure to these accidents appears to be the greatest, and the disasters most fatal. This arises from the greater length of the voyages or routes of the several boats; from an undue pressure sometimes employed; from the necessity of frequent and protracted delays at the several landings, and in procuring wood; from the impurity of the waters; from a long continued and improper inclination or careening of the boat; from a deficiency in the supply of water, and, perhaps, from unknown imperfections in the boilers. The general form and structure of the boilers in common use in that quarter, I consider to be good, and if the flues do not exceed a diameter of 13 inches, and are made to pass through both heads of the boiler, may be deemed sufficiently safe under careful management.

Several of these boilers are placed side by side, with the communications for water and steam open between them, with one fire acting under the

whole, and the worst accidents are stated to have occurred from the decline of water to the lowest side of the boat, leaving the upper boiler exposed; and I have known the same effect (a deficiency of water in one boiler) produced by the unequal application of heat while the water communications were left free. I now use four boilers of a similar kind in one boat, but with an arrangement by which such exposure is prevented. The feed water is received from the pumps by a large pipe (8 inches diameter) which passes through the centre of the furnace, and in which the water is partially heated. On the top of this pipe, where it projects into the fire room, and near the head of the boiler, are placed two double cocks, fitted to the pipe by a flange, so as to receive the water between the two stops, and impart it in opposite directions. Each of these double cocks communicates by copper pipes from its two opposite ends, to two several boilers, each stopper thus controlling the supply of one boiler. In ordinary cases, the whole are left open, and the water free to regulate its own level; but, in case of exposure to inequality by unequal heat, by careening or otherwise, the engineer closes part or all of these cocks, and (each boiler being furnished with try cocks) regulates the supply of each at his pleasure. With these precautions, I esteem such boilers to be both safe and efficient, and do not deem it at all necessary to control, by a valve, the communications between each boiler and the steam pipe. I think it important to blow off water from each boiler several times in a day, while running by a cock placed in its supporter at the end opposite to the furnace, the supporter being provided with a passage and pipe for that purpose. This is particularly useful while running in sea water, or in muddy rivers.

There is one other source of danger which I have not hitherto seen noticed, which may, perhaps, be entitled to a conspicuous place among the immediate causes of the explosion of steam boilers. In manufacturing boilers, the plates are prepared for joining by punching rivet holes in a line with each other, at suitable distances, by means of a powerful pressure, and without heating the plates. The portion of metal immediately contiguous to these perforations, is necessarily strained in the operation; and this ill effect is subsequently increased, first, by driving in a steel pin or fid, for the purpose of forcing the holes to match each other more perfectly in the two sheets which are to be united, and afterwards by being filled with a closely hammered rivet, the whole, when finished, bearing a close analogy to the process used for breaking out and separating masses of solid rock in quarries. It is true, that, should any cracks appear, the plate would probably be rejected, and that joints so formed will generally remain united when other portions of the boiler are rent by an explosion. But it is also true that a break or separation of the plates in a line with the rivet holes, often takes place, by insensible degrees, after the boiler is put in use; and in several of the exploded boilers which I have examined, cracks or separations, apparently of this sort, have been found at the very point at which the disruption has appeared to have commenced. As these joinings, together with the rivets, form a much thicker mass of metal than the other portions of the boiler, the heat received is not so readily imparted to the water, and the temperature and expansion is consequently greater than elsewhere, tending, in some degree, to separate the metal forcibly in the line of rivets, as rocks are separated by driving a line of wedges in the case, for illustration, above mentioned. Every interstice between the sheets and the rivets at these joinings has, in the mean time, become filled and solidified, and this ex-

panding or distending process continues to take effect, in some small degree, at every heating which the boiler receives. I find that this species of defect needs to be more closely sought after than any other to which boilers are commonly subject. These gradual fractures are sometimes extremely difficult of detection; and I have known cases in which, after having been carefully traced to what was supposed to be their utmost limit, they have proved, on repairing, to be of double the extent anticipated, reaching even to 15 or 18 inches. This cause, alone, may therefore be considered sufficient to account for many accidents otherwise unexplained. The evil might probably be lessened by punching the plates while at a red heat, and is to be guarded against by a frequent and careful inspection by the engineers.

Much prejudice exists against the use of cast iron heads in small boilers carrying high pressure; and if the description of such heads, as I have seen mentioned in connexion with some western accidents, were to govern, I should say that they ought to be prohibited. But if boilers of from 36 to 40 inches diameter be furnished with cast heads of a concave form, with the arch turned inwards, having the height of its curve from four to six inches from the centre of the chord, with wide flanges projecting outwards, and secured by double rows of rivets to the external cylinder, and with two straight flues passing through each head, riveted in the same manner, and the ends of the same walled up, with separate connexions for the passage of the fire, the heads not being exposed to its action, I must pronounce such heads to be far more safe than any wrought iron head which I have ever seen attached to a boiler. Such are the heads of the boilers which I have now in use; and if I should hereafter adopt a different mode of construction, it would not be for want of confidence in the entire security of this arrangement.

In attempting to classify the boats in which accidents have occurred, I arrange them as follows:

1st. *Boats having boilers of proper strength, and in a sound state, but which have exploded for want of sufficient water, owing to some fault or deficiency in the apparatus, or to want of attention.*

The Etna and a few of the western accidents may be placed in this class, and *possibly* some of the low pressure explosions.

This class of explosions is probably the most destructive.

2d. *Boats having boilers of a proper construction as regards strength and supply of water, but which have been subject to some unknown and unsuspected defect.* A considerable portion of the western accidents, and *probably* a few of the low pressure accidents on the Atlantic waters, are believed to belong to this class. The effects, though generally less violent, may sometimes be equally disastrous with the former class.

3. *Boats having boilers of obsolete or faulty construction, being intrinsically weak, and unfit to carry so great a pressure as that to which they are made subject.* A very large portion of the accidents which have occurred in the Atlantic States, have *certainly* been of this description.

The hazard from this source has, however, been greatly lessened, as few or no boilers of the most objectionable kind remain now in use, and experience has induced juster views than formerly prevailed in relation to their construction. Accidents of this class are, generally, less hazardous *to passengers* than those of the two former classes.

The contests for speed or practice of *racing* between rival steam boats, has been the cause, and perhaps justly, of considerable alarm in the com-

munity. It is remarkable, however, that as far as the information of the writer extends, there has no accident occurred to any boiler which can be charged to a contest of this sort. The close and uniform attention which is necessarily given to the action and state of the boilers and engines, in such contests, may have had a tendency to prevent disaster. But this hazard, as well as the general danger of generating an excess of steam, is greatly lessened by the known fact, that in most steamboats the furnaces and boilers are not competent to furnish a greater supply of steam than can be used with safety, with an ordinary degree of attention on the part of the engineers.

The magnitude and extent of the danger to which passengers in steamboats are exposed, though sufficiently appalling, is comparatively much less than in other modes of transit with which the public have been long familiar; the accidents of which, if not so astounding, are almost of every day occurrence. It will be understood that I allude to the dangers of ordinary navigation, and land conveyance by animal power on wheel carriages. In the former case, the whole or greater part of both passengers and crew are frequently lost, and sometimes by the culpable ignorance or folly of the officers in charge, while no one thinks of urging a legislative remedy for this too common catastrophe. In the latter class of cases, should inquiry be made for the number of casualties occurring in various districts in a given number of years, and the results fairly applied to our whole population and travel, the comparatively small number injured or destroyed in steamboats would be matter of great surprise to those not accustomed to make such estimates upon passing events. It is also worthy of notice, that if the average annual loss of life by the electric stroke were ascertained in the manner above proposed, the results would probably show a loss of life by this rare casualty far exceeding that which is occasioned by accidents in steamboats.

The means of securing safety to the travelling public has long occupied the professional attention of the undersigned; and perhaps the only safeguard which can be entirely relied on in all possible cases, has formerly been introduced under his particular direction. This consists in employing a separate boat, of safe construction, for the sole accommodation of the passengers, which is towed astern of the boat containing the engine, which last is also furnished with every security against disaster which is deemed to be, in any degree, effectual. Two of these passenger boats, or *safety barges*, were employed on the Hudson river during the season of summer travelling from 1825 to 1828 inclusive, and subsequently in 1830, and performing, for the most part, daily passages between the cities of New York and Albany. The unexpected improvement which has been made in the speed of single boats, and the unequivocal preference given by most persons to boats which have exhibited the greatest speed, has rendered this mode of conveyance, for the present, unproductive. For a more particular description of these boats, as a means of safety, I beg leave to refer to the annexed printed circular marked C.

It may prove highly useful to draw forth, in the manner proposed by the department, the facts and suggestions which may be furnished by practical men who are placed in different circumstances and localities, and possessing various facilities for correct observation. On the general question of the propriety of legislative provisions intended to secure the safety of passengers, the opinion of the writer is decidedly against the utility and expediency of such enactments. Should prescriptive rules be enacted for the

construction and management of steamboats, they would necessarily be of partial operation, and, however well adapted to the present views and practice of particular localities, or classes of artificers, would necessarily prove injurious to others, and hurtful to the public interests, while they would necessarily fail to afford the security desired, and would, in many cases, probably operate to increase the evil they were intended to remedy. If reliance is to be placed upon examinations and inspection by officers duly authorized and appointed for that purpose, the same evils, in an increased degree, would result from delegating discretionary powers to such officers, whose peculiar views would probably be ill adapted to the great variety of cases which must necessarily be presented for their examination. To penal enactments there are still stronger objections; and I know of no active branch of business to which they might not with more propriety and advantage be applied. These views, it is believed, can be satisfactorily sustained and illustrated in detail, were such a discussion suited to the character of this communication. Notwithstanding the terrific aspect of these accidents, and the loss of life which they occasion, the necessity of guarantees for the public security is believed to be much less than in the case of ordinary navigation, and of transport by land, before alluded to, and to the hazards of which we have long been accustomed. The moral sense of the community would not fail to be shocked at the suggestion of such enactments in the latter cases, as are, from the influence of nervous temperement, or a want of general acquaintance with the subject, often suggested for the regulation of the former. So far, also, as the imposition of motives upon owners, and all others concerned in the management of steamboats, for securing their safe navigation, is concerned, (which would undoubtedly be a chief object of any legislative interference) I apprehend that no motives could be imposed so lasting and so effectual as those already furnished by these melancholy casualties.

The only class of regulations which in my view would prove advantageous to the community, relate to the precautions and rules necessary for boats passing each other in the same or in an opposite direction. An elevated light should be kept at the stern of the boat, and a low light at or under the bow, at all times in the night, whether under weigh or at anchor; which will indicate to others, with unerring certainty, the course and position of the boat. Boats meeting each other on the same track should be required to *keep to the right*, and those sailing in company should be required to keep at a suitable distance from each other, and should especially be prohibited from crossing each other's track for the purpose of preventing a rival boat from getting a head. Of the enactments in relation to steamboats, which exist in this State, those only which are comprised in the above suggestions are believed to be at all useful or necessary.

I am, sir, with much respect,

Your obedient servant,

WM. C. REDFIELD,

Agent of the Steam Navigation Company.

Hon. Louis M'Lane,

Secretary of the Treasury.

A.

LIST of Steamboat Explosions which have occurred in the United States, (with remarks thereon,) by W. C. Redfield.

High Pressure.

When explo.	Names.	Place of explosion.	Killed, &c.	Wounded.
1817,	Constitution, - - -	Mississippi, -	13 killed.	
"	General Robinson, -	do. -	9	
"	Yankee, - - -	do. -	4	
"	Heriot, - - -	do. -	1	
1824,	Etna, - - -	New York bay, -	13	
1828,	Grampus, - -	Mississippi, -	Unknown.	
"	Barnet, - - -	Long Island Sound,	1 killed.	
1830,	Helen McGregor, -	Mississippi, -	33	14 wounded.
"	Caledonia, - -	do. -	11	11
"	Car of Commerce, -	Ohio river, -	28	29
"	Huntress, - -	Mississippi, -	Unknown.	
"	Fair Star, - -	Alabama, -	2 killed.	
"	Porpoise, - - -	Mississippi, -	Unknown.	
			115	54

Low Pressure.

When explo.	Names.	Place of explosion.	Killed, &c.	Wounded.
Pre. to 1825,	Enterprise, cop. boiler	Charleston, S. C. -	9 killed,	4 wounded.
"	Paragon, do. -	Hudson river, -	1	1
"	Alabama, - -	Mississippi, -	4	
"	Feliciana, - -	do. -	2	
"	Arkansas, - -	Red river, -	4	
"	Fidelity, cop. boiler	New York harbor	2	
"	Patent, do. -	do. -	5	2
"	Atlanta, do. -	do. -	2	
"	Bellona, do. -	do. -	2	
"	Maid of Orleans, do. -	Savannah river, -	6	
"	Raritan, unknown -	Raritan, - -	1	
"	Eagle, do. -	Chesapeake, -	2	several.
"	Bristol, - - -	Delaware river, -	-	1
"	Powhatan, cop. boiler	Norfolk, - -	2	
1824,	Jersey do. -	Jersey city, -	2	
1825,	Tesch, - - -	Mississippi, -	several.	
"	Constitution, - -	Hudson river, -	3	
"	Legislator, - -	New York harbor,	5	2
1826,	Hudson, - - -	East river, -	-	1
"	Franklin, - -	Hudson river, -	1	
"	Ramapo, in Jan. - -	New Orleans, -	5	2
"	Do. in Mar. - -	do. -	1	1
1827,	Oliver Ellsworth, - -	Long Island Sound	3	
1830,	Carolina, - -	New York harbor,	1	
"	Ch. J. Marshall, cop. boiler	Hudson river, -	11	2
"	United States, - -	East river, -	9	
1831,	General Jackson, -	Hudson river, -	12 Supposed	13
			95	29

N. B. Of the above low pressure explosions, ten were copper boilers, from which were, killed 42, wounded 7.

8 iron boilers, - - - -	do.	35,	do.	3.
9 boilers, metal unknown, (probably iron)	do.	18,	do.	19.

The number of copper boilers in use is now very small compared with those of iron.

LIST—Continued.

Character of Engines not specified.

When explo.	Names.	Place of explosion.	Killed, &c.	Wounded, &c.
	Cotton Plant, -	Mobile, - -	Unknown.	Unknown.
1816,	Washington, (high p.) -	Ohio river, -	7 killed,	9 wounded.
1826,	Macon, - - -	South Carolina, -	4	
1827,	Hornet, - (low) -	Alabama, -	2	2
1826,	Susquehannah, - -	Susquehannah, -	2	
1827,	Union, - (high) -	Ohio river, -	4	7
1830,	Wm. Peacock, stovepipe	Buffalo, - -	15	
"	Tally-ho, - (high) -	Cumberland river		
"	Kenhawa, (low) -	Ohio river, -	8	4
"	Atlas, - - -	Mississippi, -	1	
"	Andrew Jackson, -	Savannah river, -	2	
1831,	Tri-color, (low) -	Ohio river, -	8	8
			46	21

RECAPITULATION.

		Killed.	Wounded.
13	High pressure accidents, - - - - - -	115	54
27	Low pressure do. - - - - - -	95	29
12	Character of engines unknown, supposed to be chiefly high pressure,	46	21
52	Total,	256	104

In some of the principal accidents comprised in the foregoing list, the number of killed includes all who did not recover from their wounds. In other cases, the numbers killed are as given in the newspapers of the day, and some of the wounded should perhaps be added. In some few instances no list has been obtained, and possibly in some no loss of life has occurred. The accounts of some of the minor accidents may have been lost sight of or overlooked in my files. *In making an approximate estimate of the whole number of lives which have been lost in the United States by these accidents, I should fix it three hundred.*

Although this is a melancholy detail of casualties, yet it seems less formidable when placed in comparison with the ordinary causes of mortality, and especially when contrasted with the insatiate demands of intemperance and ambition. It is believed that it will appear small when compared with the whole amount of injury and loss which has been sustained by travelling in stages and other kinds of carriages. More lives have probably been lost from sloops and packets on the waters of this State since the introduction of steamboats, than by all the accidents in the latter, though the number of passengers exposed has been much smaller. In one case that occurred within a few years, thirty-six persons were drowned on board a sloop in the Hudson river, and many instances, involving the loss of a smaller number of lives; and one case occurred not long since, on Long Island sound, which resulted in the loss of twelve or fourteen individuals.

It will be seen by reference to the foregoing list, that, of twenty-five lives that have been lost on board of New York steamboats, previous to the case

of the Chief Justice Marshall, and excluding the case of the Etna, only *one passenger* is included in the number. Even in the more fatal cases which are here excluded, and in all accidents of this nature, the chief loss is sustained by the crew and officers attached to the boats, who, by the nature of their employments, are compelled to encounter by far the greatest portion of the hazard.

An earnest and persevering attention to the safety of steam boilers, and strict personal inquiry into the accidents which have occurred, enables me to state fearlessly, though in opposition to received opinions, that, since the year 1824, no accident in this region has been justly chargeable either to want of water in the boiler, or to culpable negligence or incompetency; but every one has arisen from *the defective form and structure of the boilers* which have failed. Some *of the most* careful and meritorious of the engineers and attendants have suffered at their posts, and have sunk into their graves under imputations as unmerited as they were gratuitous and cruel. Nor can a resort to legislative enactments either remedy the evil, or afford any additional security; but the matter must be left to the intelligence of the age, and to the operation of motives which are more powerfully felt by the owners and managers of steamboats than any which legislative authority can impose.

Notwitstanding the multiplication of steamboat accidents during the last and present seasons, still the hazard, or average loss of life, is constantly diminishing, and will probably continue to diminish in a still greater ratio as soon as the large ill constructed and unsafe boilers which were in vogue a few years since, under the soothing cognomen of *low pressure* boilers, shall have been finally discarded; in which result considerable progress has already been made.

The amount of steamboat business in this country has been increased immensely since 1824; and perhaps exceeds the average of the preceding period by fifty or one hundred fold. In the spring of 1824, but one steamboat ran in the waters of Connecticut; and but two from New York, eastward, and with a small number of passengers compared with what they now carry. Now we have sixteen or twenty in full activity in that direction. One boat on the Hudson, built in 1825, has carried near two hundred thousand passengers; and we have sixteen or eighteen boats plying on the Hudson, while, southward from this city, the change has been equally great. (American Journal of Sciences and Arts, vol. xx, page 336, with subsequent corrections.)

B.

On the supposed Collapse of Steam Boilers, and the means of preventing explosion, by W. C. Redfield.

New York, *September* 24, 1831.

To the Editor:

Dear Sir: The review of Professor Renwick's Treatise on the Steam Engine, which appeared in the last number of your valuable Journal, contains the following passage:

"A great proportion of the fatal accidents which have occurred in steamboats has arisen from a *collapsing of the boilers;* that is, in consequence of the sudden formation of a vacuum in the boiler, by which means the sides of the boiler have been crushed together by external pressure, and the

hot water and steam forced out with great violence. It seems a very easy matter to provide against this source of danger, by attaching to the upper parts of the boiler an air valve opening inwards. Whenever the tension of the steam becomes less than the pressure of the atmosphere, the valve will open and restore the equilibrium."

As a just apprehension and estimate of the facts is of great importance in guiding our inquiries on this interesting subject, I am induced to state my impression that no fatal accident has occurred to any steamboat in the American waters, which can justly be ascribed to the cause mentioned in the foregoing paragraph. In all the accidents which have happened in this quarter, the boilers have been crushed or broken through *in the direction which is opposite or contrary to the pressure of the atmosphere.* It appears, also, from the best evidence which we can obtain, that the pressure of steam at the time of these accidents, as well as on ordinary occasions, has *exceeded that of the atmosphere* by a pressure of from seven to seventeen pounds to each square inch of surface, and, in some instances, by a much greater force. It deserves also to be mentioned that most of these boilers were furnished with "an air valve opening inwards," for the special purpose of obviating any danger which might be supposed to arise from such a source.

The indeterminate use of the word *collapse* by persons attached to steamboats, and by those who have given accounts of these accidents, has probably occasioned most of the misconception which appears to prevail on this subject. Most of the boilers which have failed in this vicinity, were so constructed as to contain large internal flues, (often more than six feet in diameter,) which were broken in by the external pressure of the steam upon them; and the term *collapse* has been used merely to designate the direction in which the disruption has taken place, or rather to indicate the portion of the boiler which sustained the injury.

To illustrate clearly the causes of failure in those boilers which have come under my own observation, would require a prolixity of detail which is not suited to the object of this communication.

The statement of Professor Renwick, that in our American steamboats "there is never but one safety-valve," and that "plates of fusible metal are unknown," is somewhat too broad, and is calculated to mislead the public in regard to the actual state of what may be called practical science in this country. Fusible metal was several years ago applied to boilers as an additional mean of safety, under the directions of the writer, and was also used in other boats navigating from this city. (Most of the steamboats with which I am acquainted are also furnished with two safety-valves.)

Although the strictest attention to the means of safety in steamboats cannot be too often or too strongly urged upon those who construct or navigate them, still it is true that much unmerited censure has been dealt out to this class of persons, not only by the ordinary periodical press, but sometimes through the medium of scientific works of a more permanent character. It should always be recollected that an undivided and careful attention to one or two safeguards, of known and acknowledged efficacy, will, in ordinary hands, afford a much greater degree of safety than can be secured by the adoption of all the contrivances with which curious or learned men have, from time to time, become interested. A due regard to *strength* in the form and structure of boilers, will remove all reasonable grounds of apprehension, in regard to a mode of travelling which is already the safest, on the whole, of any with which we are acquainted. (American Journal of Science and Arts, vol. xxi, page 190.)

No. 4.

Report on steam boilers, by Thomas W. Bakewell.

CINCINNATI, 1*st Nov.* 1830.

SIR: A copy of your letter to Morgan Neville, Esq. of this place, together with a list of interrogatories relating to the explosion of steam boilers, have been placed in my hands by that gentleman, with a request that I should give such information in reply to them as I may possess. The interrogatories appear to be addressed more particularly to those who may have been present at an explosion of a steam boiler, and to relate to the circumstances growing out of a disaster of that kind.

As I have never been present at an explosion, I shall proceed to the subject, apart from the order in which the interrogatories are made. It is desirable that a statement of this nature should be composed of as much of fact, and as little theory, as possible, and the subject has, consequently, engrossed my attention for several months, in obtaining such information as might enable me to present a full narration of facts attending many of the explosions on the western waters; but in this I have been disappointed, owing to the confused and contradictory statements of the parties present.

I am therefore compelled to rely in a great measure on the impression made on my mind by the several accidents at the times respectively when they occurred, with the consequent risk of my report being biased by my own peculiar views.

I have been theoretically and practically acquainted with the steam engine, both in the making and using of that agent, for nearly 20 years. My experience in its use has consisted chiefly in its application to boats; and I believe no alteration or improvement, either real or pretended, during that period, has escaped my notice.

I have every reason to believe that most of the explosions of boilers arise from the simple fact of the steam being urged to a density beyond the strength of the boiler, unconnected with the production of hydrogen gas, or any sudden chemical change in the constituent parts of water, but that explosions have occurred when the steam has not been above the usual working pressure, and under circumstances which cannot be explained, but by admitting the rapid production of some kind of gas or steam, in quantities too great to be carried off by the safety-valve. The *immediate* cause of this last species of explosion cannot, with certainty, be known. It is, however, generally agreed that it never takes place, unless, from a want of a sufficient supply of water, certain parts of the boiler or flues become red hot. The steam, also, in this case, will sometimes be so much heated, as to set fire to the deck, or any combustible substance in contact with the boilers; and the steam admitted to the engine in this state, will burn the hempen packing and wood contiguous to the engine.

To the above effects I have been an eye witness, but no explosion ensued. And here I would observe, that, although there exists a difference of opinion as to the proximate cause of explosion, in a boiler thus circumstanced, it is generally agreed, that to inject water before the fires shall have been extinguished a sufficient length of time for the boiler to cool, is the most dangerous step that can be taken.

The two opinions as to the cause of explosion by injecting additional water into or agitating that already in the boiler, in this heated state, are, first, the oxidization of the hot iron, and the consequent disengagement of

hydrogen gas, which, by its subsequent combustion, creates the explosion of the boiler.

The other opinion is, that the rapid production of steam is of itself sufficient to account for the effect, and that, if hydrogen gas be generated, it acts, by its expansive force, as a gas, in addition to the steam; and in corroboration of this view of the case, it is alleged that copper boilers have exploded under circumstances which might well have been attributed to the combustion of hydrogen gas, had not the material of which they were made precluded the idea.

The only case in the western waters, which we are compelled to refer to one or other of the last two mentioned causes, is that of the steamboat Grampus, whose boilers, six in number, cylindrical, thirty-eight inches diameter, with two fourteen inch flues in each, exploded simultaneously about daylight in the morning; and, after, it was discovered that they contained very little water, and a plentiful supply was suddenly thrown in. It is said, but not well established, that a smoke and smell of burning was perceived before the explosion.

Several explosions have taken place, by suffering earthy sediment to accumulate on the bottom of the boiler. This sediment will in time become heated, or baked to dryness, and the contiguous metal attain a red heat, and, when thus weakened, is incapable of sustaining the ordinary pressure of steam.

The late accident on board the steamboat Caledonia was from this cause; but the most frequent cause of explosion has been from the direct pressure of the steam, without recurring to others more remote or occult. Owing to explosions having taken place after the engine has made a few strokes, the idea has obtained, that the steam was not at the highest point at the instant of explosion; moreover, it is contended, that explosions have taken place at starting, when the steam was certainly not higher than it had frequently been.

It will be observed, however, that when a boat is *about to start*, it is usual to prevent the further escape of steam by the safety-valve, and to urge the fires, and that owing to the gradual and slow motion of the engine for some time (say half a minute) after starting, that the steam is generating faster in the boiler than is demanded by the engine, and that the point of time when the steam is at the highest pitch is more frequently over half a minute than under that period of time.

It is also known that a boiler, or iron shaft, or other piece of machinery, will give way by a continued strain, which strain shall be less in degree than would be sustained for a short time without injury, and that it by no means follows that when a boiler explodes by excess of steam, that it never had previously been subjected to an equal pressure.

I am not aware of any instance where two successive and distinct explosive efforts have been detected, as alluded to in your last query. This, however, was stated to have been the fact, in the explosion at Bowen's mill, at Pittsburg, in 1821. I had satisfied myself, by personal investigation at Pittsburg, that this report was erroneous; and in a description of that disaster, lately received from Mr. Bowen, the idea is again refuted. The boiler gave way at the bottom over the fire, and was known to contain sufficient earthy matter to warrant the conclusion that the baked sediment was the immediate cause of the explosion. The usual source for the supply of water had been interrupted, and the boiler supplied for three days previous with water from a muddy well.

An explosion took place about eighteen months ago in McNickle's mill, at Pittsburg, under circumstances so similar to that at Bowen's, that it is fair to attribute them both to similar causes. It was known in both the above cases that there was no deficiency of water.

By the aid of a few figures, (not necessary to introduce here,) it would be easy to show that the steam alone was much more than adequate to the effect, or the projecting of the boilers from the mills. As an instance of the difficulty in arriving at the truth in occurrences of this kind, allow me to state that, in the year 1827, the steamboat Union, Captain Clark, when a few miles below this place, burst off one of the cast iron ends of her cylindrical boilers, three feet diameter.

The after end, which flew off, passed, together with water and steam, through the cabin, tearing down all the light partitions which intervened, and laying open the cabin by parting its sides from the deck above. The boiler, by the unbalanced pressure, or reaction, after the end flew off, was projected over the bows of the boat into the river.

The boat was shoving off from the shore at the time, and about to start; but, as far as I can learn, the wheels had not made a revolution.

I saw the captain and some of the crew soon after the accident, who assured me there was plenty of water, for he (the captain) saw the gauge cocks tried, two minutes before the explosion.

But at a subsequent period, and after the captain had conversed with some of those who contend that a boiler cannot burst with "fair play," as it is termed, he became of the opinion that the cause was a deficiency of water, and the flue being red hot, and did not doubt of its being collapsed, and that the formation and combustion of inflammable gas, or some other hidden and uncontrollable circumstance, produced the explosion. The history of the case rested on these grounds, until the boiler was recovered from the river, when it was seen that the flue and interior of the boiler were perfect, and exhibited no signs of having been heated red hot. A thin whitish coating of earthy (probably calcareous) matter was on the upper part of the flue, which some at first sight supposed to indicate having been heated, but this appearance is observable on all flues after the water is drawn off from the boilers, at the same low stage of the river.

The flue in this boiler did not pass through the end which was forced off, but turned down by an elbow, short of the end, to receive the heated air and smoke from the furnace below. The steam was usually worked at about 80 lbs. to the inch; and at the time of the accident the Union was in contest with another boat.

The principal reason of explosions having been more frequent of late on the western waters than formerly, is simply because the engineers work the steam higher, and this they are enabled to do with the same boilers, by cutting off the steam shorter, not only with cams suited to that end, but by "pinching" the steam at the throttle-valve.

This mode of proceeding, together with the prevailing notion, as before stated, that boilers will not or do not burst by "fair play," that is, by the pressure of the steam alone, with plenty of water, has been the main source of the recent disasters.

The success which has attended the British act of Parliament, predicated on the most direct and obvious view of the case, to wit, that boilers burst because the steam is too strong, or the boiler too weak, is deserving of our serious consideration. That act provides that every boiler shall be tried

by hydrostatic pressure, to bear three times the strain, which shall be indicated by an extra certified safety-valve.

The details of the examination inducing this act may be found in "Partington on the Steam Engine." London edition of 1822.

I conceive that this very severe test secures the boilers from explosion, not only from the pressure of steam, *with* a sufficient supply of water, but in all ordinary cases *without* a proper supply. For with this required extra strength, the flues of most boilers would sustain the working pressure at a red heat; and the boilers of the English boats are exempt from one of our sources of accident, viz. the gradual wasting and weakening of that part of the bottom of a boiler, which with us is so commonly exposed to the action of the fire, and kept in a red hot state by baked and dry earthy sediment over it. The bottoms of their boilers, where the sediment settles in injurious quantities, are not exposed to the action of the fire, any more than those of most of our eastern boats; and a very slight test of strength beyond that allowed by the safety-valve of the "Chief Justice Marshall" would have shown that the lower part of her boiler, or large flue, was insufficient to stand the fair pressure of the steam, though not exposed to the fire.

If a test, equally severe with that of the British act of Parliament, were required in this country, nearly all our boats, both eastern and western, would be rendered useless; and it therefore remains to be considered to what degree it may be imposed without being oppressive, in the present condition of our steam navigation.

Permit me to suggest that all boilers of boats used for the conveyance of passengers be proven, at least once in twelve months, by hydrostatic pressure, to be capable of sustaining *double* the pressure that should be indicated by an extra safety-valve, which said extra safety-valve should be under the sole control of the master of the vessel, and he be under bond and oath that no greater pressure of steam should ever be carried, than shown by the lifting of said extra safety-valve. That surveyors be appointed at convenient ports, to see to the proper and faithful carrying into effect of this measure, who should grant their certificate accordingly.

Every boat has, or may have, at a small expense, the means within herself of applying this required test, by attaching a temporary lever to her forcing pump, to be worked by hand, or a small one provided for the purpose. This test might be relied on for preventing explosions from the usual cause, (excess of steam,) and also in *most* cases when the accident takes place, from the metal being weakened by heating. I know of no legislative enactment that can provide against a deficiency of water, or an accumulation of mud or saline deposite in the boiler.

The contrivance called a "telltale," designed to give notice when the water gets too low, and sometimes made self-acting, so as to supply the boiler, is, with reason, objected to by practical men, as uncertain in its own operation, and tending to lull the engineer into carelessness and false security, and, whenever the boat should have motion from a sea, would be utterly useless. It is true, that the constant turning of the gauge cocks is an irksome office, and is apt, on this account, to be neglected. If some more easy and agreeable mode could be adopted of making the engine tender an *eye witness* to the height of the water in the boiler, it would go far towards removing danger from this source. Tubes of glass have been tried in Pittsburg and in this place, the lower ends of which communicated with the water, and the upper ends with the steam, which answered the purpose com-

pletely, so long as the tubes remained entire, but the manufacturers have not been able to anneal any tubes sufficiently to stand long in that situation. I am informed that glass, in the form of tubes, when of the required thickness to sustain the mechanical pressure to which they are exposed, will not stand the inequalities of temperature at the inner and outer surfaces, but that there is no difficulty in making a *plate* of glass stand; and I have, in consequence, ordered some plates for this purpose, which I intend to insert in the sides of a square cast iron pipe attached to the end or side of the boiler.

Of high and low pressure engines.

The comparative merit of these two kinds of engines, both as regards safety and efficiency, has become somewhat of a party question, and great caution is required in receiving the opinions of any on this point. It may therefore be expected that I should be prejudiced in favor of the one or the other; and there is no reason to hope for impartiality in the present notice of them, except so far as the opinions of others with respect to myself, and the using of both kinds of engines, may give grounds for supposed impartiality. Both these circumstances exist in favor of an unprejudiced report of them. The proportional extra strength of *all* boilers over that of the steam intended to be carried, may generally be assumed as equal, and the liability to explode as equal, but the disastrous consequences, in the event of an explosion, may be estimated to be in proportion to the height or strength of the steam at the time of the explosion. Hence it must be infered that the balance of safety is on the side of the low pressure engine, and I believe the last ten years' experience will bear out this conclusion, not so much by the greater *number* of accidents with high pressure engines, as by the greater destruction when they do happen. To the engineer, "high and low pressure" are indefinite terms. Engines, which condense the steam, (as distinguished from those which suffer it to escape in the air,) work steam at all the various pressures from five pounds to one hundred pounds on the square inch; and as good a vacuum may be obtained in the one case, as in the other, contrary to popular opinion, and that expressed in several works on the subject. The same quantity of caloric, and of steam by weight, will pass to, and be overcome by, the condensing apparatus, with the same furnace and boilers, whether the steam operate through a large cylinder at five pounds, or through a small one at one hundred pounds to the inch; but the *nett* gain by the vacuum, on every square inch of the piston, is the same in both, say ten pounds to every square inch; so that the smaller the cylinder, and the higher the steam worked, the less the vacuum becomes an object, and is consequently in most cases relinquished altogether; and then the engine is called "high pressure."

I am, sir,
Very respectfully,
Your obedient servant,
THO. W. BAKEWEEL.

To the honorable S. D. Ingham,
Secretary of the Treasury United States.

No. 5.

TRENTON, *January* 25, 1831.

DEAR SIR: In compliance with your request, I repaired to New York, and commenced the inquiry respecting the explosion and bursting of boilers of steamboats. In the first place, I called on those gentlemen most experienced and interested in steamboats; in the next place, those engaged in the making and repairing engines and boilers; also, those gentlemen of science and observation, best acquainted with the subject. All those to whom I delivered your circulars promised to give, as several expressed themselves, their undivided attention to the inquiry, and all appeared to fully appreciate the importance and benevolent intentions of Congress in the inquiry. At the same time I pursued the inquiry, by going on board all the boats in the harbor, to arrive at the cause of the different explosions that had taken place, and as the explosion of the Etna had occasioned much conjecture as to the cause, and great excitement and sympathy at the time of the dreadful catastrophe. At your suggestion, I called on several of the members of the Philosophical Society, who, as I was informed, had appointed a committee of their body to investigate the subject; but, upon inquiry, I found, although a committee had been appointed, they had never been able to obtain facts sufficient to form a report upon. Anxious to arrive at the truth of this interesting explosion, I made diligent inquiry for the captain, who, I was informed, had removed to the State of Delaware. I also endeavored to find the engineer, and went to Brunswick, where I was informed he was at that time a stage-driver on the Union line, and, having had but a very limited experience as an engineer, would not be able to give any satisfactory intelligence on the subject. In pursuing the investigation, I fortunately became acquainted with a Mr. Shepherd, an engineer on board the New York, who gave the following account of the explosion, viz.

The engine was on the high pressure principle, and had three boilers; that the boilers were placed longitudinally beside each other; the supply of the water to the middle boiler had become obstructed, and the fireman observed the boiler to be much heated, and surrounded, as he said, by a blue flame. The stroke of the piston was much slower than usual. The fireman, becoming alarmed, called on the engineer, who, ignorant of the remedy to be applied, ordered the fire to be kept up, as the boat was losing her speed. At this time, the boiler was observed to be at nearly a red heat, and immediately the explosion took place. On inquiry of a person who was at the time a passenger, whether he observed any thing unusual previous, he answered, that, immediately preceding the explosion, a snapping and cracking, of a remarkable shrillness, was noticed by several passengers. In the case of the Etna, the engineer had been a few days before discharged, and replaced by a person altogether ignorant of the principles of steam engines, having previously been a mason or house plasterer.

The next object of inquiry was the Chief Justice Marshall. The great difficulty of arriving at any satisfactory explanation from passengers at the time on board, or those interested in boats, made it necessary to take a number of passages on board of the boats, to arrive at truth from the firemen and the hands on board. For this purpose I found it expedient to take passage in the Marshall to Newburgh. I found it impossible to arrive at any satisfactory information from those employed on board of the boats; and the opinion from the passengers is of a conflicting character, particularly those

on board at the time the explosion took place, the alarm at the time depriving them of all the interesting circumstances necessary to form a correct opinion. On inquiry among the citizens of Newburgh, they stated that the steam, as it issued from the steam pipe, was of a peculiar shrillness, and appeared of a deep purple color; that, upon examining the boiler, it appeared as if it had been heated to a great degree. I, on returning to the city, called on the person who had examined the boiler, (Mr. Allair, extensively engaged in making steam engines,) who stated that it was evident the water had been suffered to get too low, and the rent exhibited evident proof of having been exposed to intense heat, and that the explosion must have arisen from carelessness in the engineer.

I also examined the situation of the United States immediately on her return to the city. This was a case different from the others, and appeared to arise from excess of steam, and was occasioned by a collapse of the flue, from not being sufficiently braced. In conversing with the captain, who appeared to be a candid, judicious man, he stated he could not account rationally for it, as but a minute before he had examined the gauge cocks, and found a sufficient supply of water. The engineer stated he had also examined the state of the water in the boiler but a few minutes before the explosion. I endeavored to find some of the passengers, and, from amongst a number, I found but one who appeared capable of forming a correct opinion, who corroborated the statement of the captain and engineer, as he had observed the captain and engineer examine the gauge cocks immediately before the explosion. He further stated that the boat was evidently under a high press of steam, and that the solicitude of the captain and engineer frequently examining the cocks gave him some alarm, as the boat was running in opposition to one on the opposite side of the island, and that previous to the accident there was a strange tremulous motion of the boat, an evident shuddering several times in succession, previous to the explosion. This is a case which may be classed under the one of a boiler bursting, or the flue collapsing, from excess of steam.

The dreadful explosion in New York, at McQueen's furnace, was evidently of a different character, and was owing to a deficiency of water. I went to the place immediately on hearing of the explosion; and, from the statement of Mr. McQueen, I was satisfied it arose from the ignorance of the person who had the charge of the engine, having been hired, a few days previous, for six shillings a day, and having no knowledge of the principles of steam. The men who worked in the furnace stated that the motion of the engine had become so slow that they repeatedly called on the engineer to keep up the fire, as the machine was going so slow they could not execute their work, and that immediately the explosion took place. Upon examining the boiler, there was evident proofs that the boiler had been heated to nearly a white heat, as the rivets were of a deep blue color, and the rupture took place five feet from the end, throwing the end, weighing seven or eight hundred pounds, across the street, into the second story of a house opposite, carrying with it the whole side of a two story building, killing a man passing in the street, as also the engineer. This case belongs to the class of explosions, and was accounted for by a very intelligent person, who informed me, that once being on board a boat, he observed the water to be so low, that having heard it remarked that steam, at a high state of temperature, was capable of combustion, he tried the gauge cocks, and, on applying a candle, it burnt with great brilliancy. Does not this fact explain the phenomena of

explosion? When the deficiency of water takes place from some obstruction in the supply pipe, and the steam raised to the state of hydrogen, the metal becomes red hot, and explosion takes place. The case of the steamboat at Jersey city presented some interesting particulars. The boiler was of copper, thirty feet in length, eight or nine feet diameter; the explosion was a collapse of the flue, and, when it took place, the boiler was on deck, and rose at least forty feet, and turned end for end, and bottom for top. Mr. Jenkins, the ferry master, an intelligent person, although present at the time, and on the wharf so near as to have the water reach him, but without much injury, hesitated to assign any satisfactory cause, as he said it was involved in such uncertainty as to preclude a correct conclusion. In this case there appeared no deficiency of water; and, on further inquiry, I afterwards understood the safety valve had been the day before out of order, and had been repaired, but that there was doubt of its having been correct at the time of the disaster, and that the boat being ready to start, the steam must have been raised too high.

I made every exertion to arrive at the correct account of all the various explosions that had occurred in the harbor of New York; but the length of time, and the difficulty of arriving at any correct data to form conclusions, was much greater than could have been anticipated. I made a number of passages in steamboats, hoping to arrive at a correct narrative of some of the various circumstances and causes, but, in almost every case, met with chagrin and disappointment, most frequently from ignorance, and sometimes from a fear of criminating the individuals connected in the transaction, and, in most, a cold indifference to the subject; a very few who appeared to appreciate the true motive which induced the inquiry, although I had placed the circulars in the hands of every individual whom I supposed most capable of answering the interrogatories; and every one promised to give answers to such as came within the purview of their knowledge; and, after calling repeatedly to call their attention to the subject, it is with the greatest regret I have to inform you no one has, as yet, fulfilled their promises. In pursuing the investigation, I procured letters to Mr. Kemble and Mr. Young, men of science and intelligence, and who do the most of the castings for steam engines at Cold Spring, on the Hudson river. I also procured letters to Professor Douglas, at West Point, but had not the satisfaction of meeting him, as he had left there for the Morris canal.

In accounting for the defect in the receipt of the information from those gentlemen from whom I expected most, I have come to the conclusion, that, upon investigating the subject, they have found it connected with so many difficulties, that renders it doubtful as to forming correct conclusions.. To arrive at a correct statement of any explosion, is a matter of extreme difficulty, the contrariety in the narrative arising from the difference in situation of the different individuals; the effect of alarm on many, that the various accounts are almost as different and variant as there are individuals present at the time. At the time I was endeavoring to arrive at the cause and correct account of the various disasters, I was solicitous to have the schedule of the power, tonnage, and various proportions of the machinery of all the boats in the harbor filled out, and in this I had anticipated no difficulty; but to my surprise, when calling on the captain, he frequently declared himself incapable without having the engineer present, who frequently was not on board. When making application on board the same boat, the engineer expressed an unwillingness, unless the captain was present, who was at the time in the

city. I have called on board the same boat more than twenty times, and met with similar evasions. A number of the captains I found very polite and accommodating gentlemen, who manifested every disposition to give every information in their power.

I am unable to account for the disposition to elude the inquiry in many, unless it arose from a fear that some law would follow, affecting their rights and privileges; and when endeavoring to induce a compliance with the request for information, by endeavoring to explain the benevolent views of Congress in instituting the inquiry, the answer, most generally, was, it was a concern purely individual, and one in which the Government had no right to interfere. In some it arose from an opposition to the views of the General Government; in others, from native meanness and suspicion; but, in every case, gave rise to a chagrin and disgust, which rendered the pursuit of the inquiry extremely disagreeable.

I did not consider your inquiry extended to the ferry-boats, and made no inquiries of them. I called on Mr. Robert Stevens, who stated, having received a circular, he would forward to you all the information he possessed, with an account of all the boats in which he had an interest. In a conversation respecting the cause of explosions, he stated, that, although he had been engaged in steamboats for more than twenty years, and had been interested in more than twenty steamboats, no accident had ever occurred, even to the scalding a fireman; and that those accidents which had occurred, could, in almost every case, be traced to want of skill, or want of care, in those to whom the management of steamboats was entrusted.

I endeavored to obtain an account of all the different explosions that had occurred in the harbor of New York. To arrive at satisfactory conclusions on so interesting a subject, it became necessary to take a number of passages in the steamboats to the various places where those interested resided, to endeavor to find intelligent individuals, who at the time were passengers; but, after all the industry exercised, and pursuing the inquiry through every channel which promised a prospect of success, it was impossible to arrive at any data sufficient to found a correct report upon. You must be sensible how few among the many that take passages in steamboats are capable of giving a correct or rational account of an occurrence that had taken place under their own observation. Disappointed in this course, I went to the workshops where steam engines are made and repaired, to the engineers of the several boats, but in every instance was incapable of arriving at facts of such a character as would be satisfactory to you, as they were wholly inconclusive to myself. The most of the information was hearsay and conjecture. In a number of cases, I was desirous of obtaining answers to the interrogatories contained in the circulars, but found a reluctance, almost universal, to having their names attached to an examination which might go forth to the public, which would prejudice either persons interested or engaged in boats. The time necessary to complete the inquiry was greater than I had anticipated. Most of the boats arrive in the evening, and leave early in the morning; and when at the wharf, the captains are attending to the business of the company or their families, and the opportunity of inquiry is short, and was frequently evaded by the plea of want of time.

In pursuing this interesting inquiry, I have pursued every means most probable to elicit information. I have conversed with every one that I thought most likely to give some satisfactory explanation; from the man of science to the practical mechanic; from the captains and engineers to the

fireman, from passengers on board to respectable and intelligent individuals where the accidents occurred; and the conclusions I have formed on the subject are the following, viz. Steam is an element or principle completely within the control of science, and that every accident that has occurred has originated from want of skill, or want of judgment and care; that the accidents that have occurred, in most cases, have been where engineers of experience have been replaced by ignorant or careless individuals, who are obtained for a less compensation. Various opinions are entertained, by many experienced in steamboats, on the expediency of compelling the owners to have boilers of sufficient proof. In the cases of explosion, no strength would be sufficient to resist the power created in the bursting from an excess of steam; it would, no doubt, prevent it in some cases. In the communications which you, no doubt, will receive, you will be able to draw conclusions on the subject more satisfactory than mine. Enclosed I send you the schedule of the principal boats in the waters of New York, with the exception of Mr. Stevens's, which he stated he would forward, as he had received your circular direct from the department. I also send you, in addition, a statement of their mechanical proportions, procured from Professor Renwick; it may be satisfactory to see the comparative character of the different boats in the country.

Respectfully, your obedient servant,

CHAS. KINSEY.

Hon. Samuel D. Ingham.

No. 6.

New York, *January*, 1832.

Dear Sir: Your letter on the subject of bursting of steam boilers, published in this city last October, was recently put into my hands: at the time of its publication, and up to November last, I was at Portsmouth, Rhode Island, (which place is my home,) and so situated as not to know of such a document being before the public. My present business, in this city, is connected with the subject-matter of your interrogatories. Some gentlemen of this city, to whom I am known, are associated under the name of the Steam Safety Company; to some of them I have made known, in part, a certain invention of mine, which I call an unerring steam safety-valve, to prevent the exploding of steam boilers. We have, for a short time, been negotiating an agreement between us, on my part, to complete my specification and take out a patent, and, on their part, to find certain funds, &c. At present I am under no contract with any one; and, since seeing your letter, I do not intend to form any connexion till I ascertain what are the views of Government on this important subject. I certainly feel sorry to see Government seeking only gratuitous information: those practical engineers, (if any there are,) whose circumstances would permit them to make the world a present of such an invention, are differently situated to what I am. I exceedingly regret that my late unfortunate connexion with the Rhode Island coal mines has made it necessary, on my part, to seek some remuneration for several years' study and much expenditure in making experiments to complete an unerring steam safety-valve; and what I propose as a preventive against the exploding of steam boilers, carries, as I believe, occular demonstration

of its ability to accomplish the end in view. The immediate good to the public at large by the general adaptation of my invention, makes me anxious it should be brought out under the auspices of the General Government, and the more so, knowing, as I do, how very tenacious are engine makers in favor of their particular patents, or plan of construction of boilers, &c.; their unwillingness to adopt any improvement, however obvious its utility, unless it is of their own invention. If required, I am very willing to submit to any reasonable sacrifice; and I believe the honorable gentlemen, who have this subject under consideration, would not be less generous on their part. I have, therefore, in this communication, revealed my invention, to aid them in their investigation; and if they decide that I am entitled to any remuneration, I throw myself into the hands of the Hon. Dutee J. Pearce and the Hon. Charles A. Wickliffe, and shall be perfectly satisfied with what they consent to on my behalf. In order that you may the better comprehend all I wish to be understood on this subject, I believe a very short historical sketch of my connexion with steam will make it more plain. While in England, in the capacity of superintendent of a very extensive coal works, I had upwards of twenty steam engines, of different constructions, all immediately under my inspection; and from 1825 to December, 1830, the time we ceased working the Rhode Island coal mines, I was part owner and superintendent, and had a high pressure steam engine, during which time, (over twenty two years,) I never had what I call an explosion, or flue collapsed, but I have had, perhaps, a hundred boilers burst. I wish you particularly to understand my meaning of *bursting*, *collapsing*, and *exploding* of steam boilers. Whenever I use the term bursting, I uniformly mean such accidents which arise from some defective boiler plate or plates badly jointed together, or some plate burnt, or the boiler wore out; this last most generally the case. Accidents of this nature occurring under a regular working pressure of steam, are seldom or ever attended with injury to persons present, and the only preventive is a frequent personal examination and unremitted attention to any known or suspected part. Whenever I use the the term *exploding* of steam boilers, I always mean those accidents which instantaneously explodes and shatters the boiler, often smashes the machinery, and frequently scatters death and destruction to all around; to prevent which, is the object of my invention. What actually causes this explosion is a question much involved in mystery, scarcely any two persons are of like opinion, except that it is by some sudden accumulation of a very destructive power, arising from some unknown combination of the peculiar property of steam, &c. Many have been the schemes and contrivances to prevent such accidents, but, as yet, all have proved abortive. I believe it is not saying too much, to assert that no contrivance which is to be operated on mechanical principles, is calculated to counteract the destructive effects which arise from a combination of chemical properties. Mr. Perkins, Professors Hare, Jones, Silliman, and others, I believe, are all agreed that you must not contend with but follow Nature to produce an unerring effect; that Nature, in all her various combinations has inherent properties which is a sort of constitutional law, as unerring in their effects as the wisdom of Him from whence they originated. That steam hath certain inherent properties, is known to every person: its most uniform feature or general and unerring prognostic is *heat;* this is a requisite in all its ramifications, and every person engaged in working steam engines knows, as steam acquires strength, it increases in an unequal ratio of heat, and might with equal propriety be called steam of

so many degrees of heat as steam of such a strength. The real strength of steam would, with less uncertainty, be ascertained by a proper thermometer than weighing it. It follows, in the nature of this inquiry, that *heat* forms the only true basis for constructing any effectual corrective against its explosive qualities. To ascertain the strength and heat of steam requisite for working any engine, suppose you was on board any steamboat when the engineer commenced making the fire, with one of her thermometers on a proper part of the boiler; say you find the water before any fire is made to be 50°; after making the fire, as the heat increases, suppose you was to mark the following points at 97°, vital heat, and at 212 you would say the water boiled, after which steam generates in quantities and soon acquires an elastic force. Suppose the apparatus which is attached to the safety-valve to weigh correctly, and you to order the engineer to place the pea weight so as to weigh, as the steam increased in force at the following points, say 10, 20, 30, 40, 50, &c. to 150 or more pounds the square inch on the safety-valve at each point of weight, with your thermometer indicating the precise degree of heat at those points of strength; you would have a gradated scale from 10, &c. to 150 or more pounds the square inch on the safety-valve. Suppose the above facts to be ascertained, and as well authenticated as the following, viz. that the following substances (metals) melts, tin 210°, bismuth 256°, lead 260°, zinc 370°, antimony 800°, brass 3,807°, copper 4,587°, &c. and if you take 2 parts tin, 3 parts lead, 5 parts bismuth, melt them, and, after their amalgamation, that compound will melt at 197° or 200°, being 12 degrees less than boiling water; this scale of points of fusion, marked by Fahrenheit's thermometer, is known to every chemist. If there was another table or graduated scale, founded on facts as above, that is, a table showing the compounds of these metals, which would melt at each point beginning at 10 up to 150 or more pounds the square inch, you would possess what I consider the requisite for making an unerring steam safety-valve; and in every case, no matter what the construction of the engine, whether high or low pressure, I propose to ascertain the utmost strength or heat required to work such engine, together with what excess or allowance above such needful power it would be safe to fix the designated point. I would then fix on a certain part of the boiler a valve as would *melt* whenever the steam acquired a power or heat exceeding such given point; when the valve *melted*, the steam would escape, and effectually prevent the accumulation of any destructive power, and become its own *safety keeper* at any designated strength; this useful and powerful agent, when thus controlled, would permit its application to be unlimited. The melting of the valve interferes not with the working of the engine, it is intended to fix the valve in a pipe above a large steam cock: when open, the steam would be in full contact with the valve till it was melted, when the steam would blow off till all the surplus quantity had escaped; the cock would then be shut, another valve replaced, the cock again re-opened. In replacing the valve, &c. it would not require above two minutes. You will, perhaps, be told, these easy fusionable metals would not do for making steam safety-valves that such compounds as must melt at the designated point is brittle. Suppose you had one of the present steam safety-valves, with the addition, on the face of such valve, of five or six studs projecting about half an inch, (not much unlike shirt studs;) with these easy fusible metals cast on the face so as to cover the studs, you will easily perceive, when the face of the valve melted, these studs would stand on what is called the seat of the valve, as so many legs. Between each would be an open space, throuhg

which the steam would issue till stopped by turning the cock beneath. This simple preventive, freed from all complication of machinery, admits of its adaptation to engines now in operation, and is alike applicable to all, of whatever shape or make. To attach this apparatus to any boiler, would not exceed the cost of twenty dollars, ($20 00,) and, when first making an engine, would not add one cent to their present cost. Every engine maker hath now in use the patterns and moulds of which this apparatus would be constructed, and this invention, if candidly construed, interferes not with any fond and cherished prejudiced plan or shape of boiler, nor does it check the spirit of subsequent research, but otherwise, and that to an unlimited extent; for if the melting of the valve is regulated by the strength and capabilities of the boiler, steam is made perfectly harmless, and aids rather than impedes any future invention. How far boiler-makers are disconnected from the accidents of exploding of steam boilers, is a question, the discussion of which would not tend to the elucidation of the subject of this communication; but I have for years observed, where the most explosions occur, there they use fuel which gives out the greatest quantity of carbon in the least time, and I believe sufficient care has not been taken in the adaptation of the boiler for the fuel intended to be used. If fuel used in generating steam was every where the same, perhaps something like a standard for making steam boilers might be adopted, and, with great care and unremitted attention, explosions prevented; but this is not, nor ever will be, the case. But this invention permits of every sort of fuel that may be found, from the equator to the poles; and, if they please, the fire place piled full, as well every variety of shape of boiler, also, any sort of apparatus to be attached to the safety-valve, for the accumulation of caloric cannot exceed in quantity the point of fusion of such safety-valve. I have frequently been asked, if steam acquires heat and strength in an equal ratio, why its upward pressure does not open the safety-valve, when its strength exceeds the weight of such valve? I answer, I *believe* it does; and if the pea weight on the safety-valve apparatus be properly calculated with reference to the strength of such boiler, and all other parts in good order, and so long as they continue in good condition, and free from disorganization, no explosive accident does occur. I might here give you my *conjectures*, and, also, refer to the corroborating *opinions* of many others; and, after all, what does it amount to? It is but *conjecture* and *opinion;* the real cause remains concealed. If opinion only was wanted, you already have every one of your inquiries answered: many there are before the public, some valuable and highly interesting documents, and others so finely drawn by inductive and abductive reasoning about chemical affinities, change of original properties, formation of other substances, &c. &c. so as to puzzle a poor practical engineer to see the connexion of such abstruse reasoning. And I am free to say, I understand neither their theory nor the real cause of *explosions*. But leaving the Eutopian and chimerical part of this question, this hunt after the philosopher's stone, and coming within the range of my own capacity, my own practical experiments demonstrate the truth of my position, that *heat* is an unerring test of the strength of steam. I have frequently melted many compound metals on my copper steam pipe, but generally common tinman's solder, and, in the bottom of my cylinder, common lead; and to what extent metals may be melted by steam, permit me to refer you to Mr. Perkins's document he wrote to Professor Jones, about his difficulties in making secure the joints of his engine. To show the advantage of adopting my views, I will mention only one out of several facts: In one of the joints of my copper steam pipe there was a very small hole, which I

caused to be stopped with tinman's solder; after which, from the repeated remarks of my engineers, I felt perfect confidence in the security of our engine. They would often remark to me "that it required the greatest care to prevent the steam getting too hot, or else that joint would melt." So far, I have proved its utility. The stopping of our work prevented the completion of what was necessary to spread on my specification before I could be entitled to a patent. I never possessed a proper thermometer to enable me to know the heat at the sundry points of strength, and consequently I did not make the table of compounds which would melt at such points; but what I propose, I am persuaded, few will be found that would condemn its feasibility. After any explosive accident, we hear much blame imputed to the engineer or his employer, and many positively assert the cause of such was either carelessness or ignorance; my experience with steam leads me to other conclusions. I am less positive, and more inclined to lenity. Explosions are too serious in their general effect to justify the conclusion of carelessness; and, as to ignorance, if the chief engineer is a practical man, thoughtful, and careful, I care little about the ability of his assistants. I have employed scores to work my engines: when they first came into my service, they scarcely knew the boiler from the cylinder, and at Rhode Island I had several that never before saw a steam engine, and I never had an explosion; but, nevertheless, such do occur, and that, too often, is painfully proved. Much more might be said, yea, very much; but after reading what I have wrote, I see much is left for you to infer from what is said; and if the ideas are caried out to their legitimate bearing, you will, I think, find the object of your interrogatories answered, that is, an invention to prevent the exploding of steam boilers. The author of this document hopes its humbleness will not militate against the cause it advocates; he trusts sufficient apologies for all its defects will be found by a reference to his occupation; and by a liberal interpretation of his motives, the particular views of all parties will be attained. A line acknowledging the receipt, will

Oblige your very humble servant,

JOHN CLOWES.

The Hon. Louis M'Lane,
Secretary of the Treasury.

P. S. I beg to refer you to the Hon. Dutee J. Pearce, member from Rhode Island, to whom I am personally known.

No. 7.

Washington, 1*st February*, 1832.

Sir: I have now the honor to lay before you a brief statement of my views upon the causes of the explosions of steam boilers, with a description of the mode of prevention which I have devised, and, to a certain extent, put into successful operation. I have taken a patent for my improvement, the drawings for which I have in my possession, and shall take pleasure in exhibiting them to you, and in making any such explanations as you may desire in relation to the subject. If my written statement, or any verbal information which I can give, will be of any use to you, or to any com-

mittee of Congress, who may have the subject in charge, I shall be happy to afford it, to the extent of my ability.

I am, with the greatest respect,
Sir, your very obedient,
JOHN C. DOUGLAS.

To the Hon. Louis M'Lane,
Secretary of the Treasury.

A statement of the causes which produce the explosions of Steam Boilers, with a description of a combination of machinery, by which those disasters may be entirely prevented.

Steam has become one of the great mechanical moving powers by which the active business of the world is accomplished, and the intercourse of social life maintained and facilitated: that it may become as harmless as it is powerful, must be the wish of every friend to the progress of human happiness.

I shall attempt, in the first place, to point out the causes which produce explosions in steam boilers, and then describe the remedy which I propose for the prevention of them, and of that waste of property, and destruction of human life, which so frequently attend these events.

First, the great agent which produces explosions is rarefied steam, which is found upon the surface of the uncovered, heated metal, when the water is propelled upwards before the steam. When any sudden removal of the steam upon the upper surface of the water takes place, by such means as the opening of the safety-valve, and allowing the steam suddenly to escape, this takes away the base which kept the water at rest, while the steam was passing through it from the heated metal, and supplying the engines. The moment the pressure is taken off from the surface of the water, the steam so formed propels the water before it to the upper surface of the boiler, in a frothy, foaming state, and, as the steam below is becoming more rarefied, keeps elevating the water as the steam is escaping. If the safety-valve is again shut, that base which was removed by the opening of the valve, is now restored; the rarefied steam, which is now greatly expanded, becomes almost a vacuum, and is annihilated by the descent of the steam from above, or by the water, and this destroying all downward pressure, the incumbent atmosphere instantaneously operates with its full force, raises the boiler from its bed, like a balloon, carrying with it every fastening by which it was bound, or else breaks it in pieces; the weight of the atmosphere compressing and crushing the boiler, until the confined steam arrives at its lowest state of compression: it then bursts the boiler with a tremendous noise. The sudden operation of the atmosphere upon the boiler, in almost every case, gives the appearance of two actions, one from without, the other from within. The sudden weight of the atmosphere upon the fusible metal, makes it bend easily outwards. These explosions would be much more frequent, were it not that the atmospherical air penetrates the boiler through the joints and crevices made by the loosened rivets and other defects in the metal.

To prevent explosion.

I add an apparatus of well known combined machinery. At each end of the boiler, a tube of three inches diameter enters it two inches above the lower surface, or surface most exposed to the action of the fire. This tube

bends upwards, and passes through the bottom of the water cistern, which is placed upon the same level with the water in the boiler. At the upper end of this tube is placed a valve, which opens inwards when the pressure is greater from without than within, but, when the pressure is greatest from within, the valve is kept shut. Whenever the pressure within gives way to the weight of the atmosphere, the valve opens, and hot water from the cistern rushes in, and fills up the boiler to its given height. The reservoir is placed above the cistern. A tube, three inches in diameter, to convey the water into the cistern, from the reservoir, passes through the bottom: upon the top of this tube, is a valve of the same diameter. In the cistern, is a float, which is of greater weight than the valve. A scalebeam connects the two. The instant the boiler takes away any of the water in the cistern, the *float* descends, and, with it, the end of the beam; this raises the opposite end, opens the valve, and admits just the same quantity of water into the cistern that the boiler took from it. The equilibrium being thus restored, the *float* of course rises, and shuts the valve. It is by means of this combination of machinery, that the formation of a vacuum in the boiler is conceived to be rendered impracticable.

Secondly, a steam piston is placed upon the top of the boiler, which is cut out, of the same dimensions with the piston chamber; this is riveted in the top of the boiler by a flange, with which the chamber is provided. The piston rod is connected by a chain or rope with the end of the extended lever of the safety-valve beam, which is a lever of the first order: and to the same piston rod, is also attached a spring steelyard, which, by means of a chain or rope working on pullies, is connected with the said beam. When the steam begins to act, it presses upon the piston dasher, and moves it upwards; this raises the spring, which shows by the index the weight of every pound of steam. When it has attained the given weight, the chain or rope attached to the end of the safety-valve lever, connecting it with the piston rod, pulls down the end of the lever which lifts the safety-valve, and allows as much steam to escape as is necessary, and then closes. The valve cannot possibly lock, for the lever is so constructed, that one pound pressure upon the end of it will lift one hundred pounds, and, of course, ten pounds will lift one thousand, suspended upon the end of the safety-valve beam, and allow the steam to escape. By this important improvement, therefore, all attention to the letting off steam, with a view to security, is rendered unnecessary; for when it has attained the given weight, it will relieve itself, without the care or superintendence of the engineer.

By the improvements here described, a boiler upon the high pressure principle is equally safe with one upon the low pressure, and both are as free from the danger of explosion as a common kitchen teakettle.

I believe that an examination of the steamboat disasters, both in this country and in Europe, and an investigation of the causes by which they were produced, would tend strongly to the confirmation of my theory; but to notice, even briefly, all the cases that have engaged my attention, would swell my letter to the magnitude of a treatise. Suffice it to say, that I have tested my theory by the experience of several months, in a steam boiler which was in operation in my own works, in the State of New York. I do firmly believe that there is no way to prevent explosions but by means of a channel of communication, for the air to enter, when necessity requires, into the space between the heated metal and the water. The air valve upon he top of the boiler is sufficient to protect the roof, when the steam is con-

densed upon the upper surface of the water. I have to remark, that when a collapse explosion takes place by means of a sudden condensation of the steam upon the upper surface of the water, it has no effect upon the bottom of the boiler; and when an explosion takes place, by means of the sudden condensation of rarefied steam between the water and the heated metal, it has no effect upon the roof of the boiler; it is found just as it was, before the disaster took place, except it may have received bruises from external objects. These are facts well worthy of observation, as they may, if properly attended to, lead to results highly beneficial to society.

JOHN C. DOUGLAS.

No. 8.

CINCINNATI, *January* 3, 1832.

DEAR GENERAL: If the enclosed communication contains merits sufficient to authorize it, please hand it to the Secretary of State, or to the committee of Congress who may have charge of the subject, and oblige

Your friend, DAVIS EMBREE.

Gen. JAMES FINDLAY,
Washington City.

The interrogatories of the Secretary of State in relation to the bursting of steam boilers, were put into my hands some time ago. Having been engaged in steam works for some years past, I have thought proper to state some views on the subject, which may be of importance. The information, however, on which I have founded my conclusions, may not have been so clearly understood as to render it a safe data on which to rely implicitly, in forming a sound theory. Yet, so far as I am informed of the facts attending the explosion of boilers, and the collapsing of flues on the western waters they may be brought under the following heads or positions, with very few exceptions.

1st. The bursting of boilers, and the collapsing of flues, take place just at starting the boat after it has laid still for some time.

2d. The boilers that have bursted on the western waters, have had cast-iron heads.

3d. The flues of boilers that have collapsed in the western country, when the head of the boiler was cast, have almost universally killed more or less persons.

4th. Where the flues have collapsed in boilers with wrought iron heads, there have been no persons injured.

5th. There is no evidence that in *all* cases of explosions of boilers, or collapsing of flues, the supply of water has been deficient.

The first position is too conspicuous to be overlooked. The fact is too well established to be considered unimportant. We ought to look for the cause. Why do boilers burst at the moment it would seem they were relieved from the pressure of steam, by the opening of the throttle-valve?

Steam, when confined so as to have no current passing over a heated body, is a non-conductor. Water is a conductor of heat, only in consequence of the motion of the particles; this motion is generally produced by the heated particles ascending, and giving place to those more dense. The water in a steam boiler is so rarefied, that it may be considered as mixed with steam,

or as containing within its body a great quantity of particles which have assumed the airiform states: the current, therefore, of the particles of water passing over the heated surface of the metal must be slow, inasmuch as the fluid and airiform states of the water are not greatly different. Yet, when a boat is stopped, and the contents of the boilers are at rest, the particles of steam will gradually arise, permitting the water to sink in the boilers, (oftentimes deceiving the engineer,) so as to leave the top of the flues bare, which, of course, becomes immediately red hot.

When the valve of the engine is opened to start the boat, the whole contents of the boilers are agitated like the contents of a bottle of porter or champaign on drawing the cork; the water rises over the flues, and millions of particles pass upon the surface of the heated metal, which converts them into steam so instantaneously, and in such quantities, as to cause the boiler to give way. Therefore, to guard against explosions, the contents of the boilers must be kept in constant agitation, either by the motion of the engine, or by repeatedly raising the safety-valve, while the steam is high; *for disasters and death lurk in stillness.*

Second. The only exception to this position, which has come to my knowledge, is the Tricolor, a low steam boiler fifteen years in use, which did not burst at the head; and the Tallyho, a boiler made of puddled iron. The cast iron heads of boilers generally crack with the heat of the furnace. The flange to which the flue is fastened, contains so much metal at a distance from the water in the boiler, that it perishes and crumbles with heat. If the boiler bursts, the head flies like a cannon ball, while a wrought iron head will only tear. I, therefore, consider the introduction of the wrought iron boiler heads as of more importance than at first view could be imagined; in fact, there is no *calculating* the advantage of that one change in our mode of building engines.

Third. The flue of a boiler, with a cast head, which collapses, must necessarily tear loose from the head, and let out the contents of the boiler.

Fourth. When the flue of a boiler, with a wrought iron head, collapses, the head springs in, so as generally to make no rent in the boiler whatever; thus injuring no person, but the owner of the boat, by putting him to cost.

Fifth. Although it is admitted, that, in most cases of explosion, the primary cause is a deficiency of water in the boilers, yet there are so many declarations on the part of those who have been present, and who would not wilfully state falsehood, going to show that there was, in the instances to which they allude, a full supply of water, that it is difficult to charge them all with being deceived. Would it not be a better course to look for some way to account for the facts as they state them? I have been induced to believe, when taking into consideration the state of the water in the boilers, (as described under the first proposition,) that its specific gravity is not sufficient to overcome the repellant qualities of the heat from the flue of the boilers, but that a coat, or atmosphere of steam, is formed round the flue of the boiler, which does not permit the water, in its fluid state, to touch it. This state of things can only occur, however, when the boilers are at rest, and the heat in the flue rapidly accumulating, for, at the first motion of the boat, or at the first opening of a valve, the whole contents of the boiler become agitated, this coat or atmosphere is broken up, and the millions of particles of water pass upon the metal, producing the effect stated: hence, I repeat, *disaster and death lurk in stillness.*

I am supported in this opinion by many simple facts. A highly heated

bar of iron, plunged into water, after being once immersed, will make but little noise or hissing, until reduced to nearly a black heat, because the water near it is converted into steam, which forms a coat or atmosphere around it. Wet your hand, and draw it over a piece of iron heated to a white heat, and it will not be burned, because the moisture on the hand is converted into steam, which intervenes between the metal, on the skin. Pour a spoonful of water on a plate of heated iron, and it will dance in air till evaporated. I, therefore, doubt whether water, in its fluid state, can be brought in complete contact with highly heated metal. Thus we may account for boilers bursting, even when the supply of water has not been deficient.

There is another consideration that is of importance in relation to the bursting of boilers; that is, the known or unknown defects of metal. Were all workmen skilful, honest, and disinterested, who make and work boiler iron, there would be but little danger of deficient iron being palmed upon owners of steamboats; but, as matters now stand, there is no inspection of boilers, and all who make boiler iron are desirous to suit the market. Those who work it, or build engines by contract, procure the article at as low a rate as possible, so that they become interested in working an article of inferior quality. The iron first made in the western country was of a different quality, and then but two serious accidents occurred for many years. Engineers, at that time, were inexperienced and run many risks. Nothing but the good quality of the metal could have saved the boilers in many instances. Some of these boilers are yet in existence, and have been used from thirteen to fifteen years. Boiler iron was then made as if life and death depended on its quality. Charcoal was used through the whole operation; the metal underwent the same process as the best hammered bar iron. The best pieces only, were selected for boiler iron; these often being worked into thin slabs, were rolled out into sheets. The best boiler iron now procured, is made from large blooms, heated by stone coal, and worked into thick slabs, then again heated with stone coal, and rolled out into sheets. A large quantity, however, is made directly from the blooms; these are heated with stone coal, and put under rollers; when reduced to large bars, the bars are cut at proper lengths for the width of the sheet. A number of them are then *piled* together, and again heated with stonecoal, and rolled out the other way. This process is apt to leave flaws in the sheet; but the worst, and most dangerous mode practised, is by taking the puddled iron with all its impurities, and working it, by the last mentioned process, into boiler iron. If strict inquiry were made, I presume it would be found that one-half of the boilers that have bursted in the western country, have been made of this kind of iron.

Thus we see a growing danger for want of proper inspectors. Public opinion, however, has done much in suppressing the use of the last mentioned iron, yet, within the present year, in this city, a large quantity of *English* puddled iron has been made up into steam boilers, generally for land engines, I admit, but some has found its way into boats.

Yours, &c.

DAVIS EMBREE.

No. 9.

Delaware City, *Nov.* 29, 1831.

Sir: Having observed your advertisement in the U. S. Telegraph, authorized by a resolution of Congress on the 4th May, 1830, making numerous inquiries in regard to steam boilers exploding, to many of which it is not in my power to reply, but, so far as in my power, I will furnish my mite of information for the benefit of the community.

I will therefore confine myself to the first query, Are you acquainted with the nature of steam engines? To which I answer, only in theory, and in having the superintendence of building one. My principal study and occupation since 1816, has been to find out the best and strongest iron suitable to all the various descriptions of machinery; among which I found the plates of iron from which steam boilers are made to be one which required the most diligent research, as also that of manufacturing the best quality of steel, (for which latter purpose we have only one iron ore in our country yet discovered, by myself.) To acquire a more perfect knowledge on this subject of iron generally, I visited Europe in 1818. On my return to America, I still continued to endeavor to procure and vend the best iron that could be found of all the various kinds; and so far as my limited intelligence has enabled me to ascertain the cause of steam boilers bursting, I am of opinion it exists in forming the boilers out of defective boiler plates.

In order to elucidate the subject, permit me to inform you of the different processes used in manufacturing what is generally termed boiler plates. The first is, converting scrap iron, that is, wrought iron which has become useless, and is purchased at about $35 per ton, promiscuously, of all descriptions, iron of a good quality and bad, mixed; these scraps are piled together, and form an oblong square, 4, 6, 8, and 10 inches thick, bound round with an iron hoop or nail rod; when the pile is thus prepared, it is placed in a balling furnace, where it is subjected to a white or welding heat; it is now removed from the furnace and subjected to the pressure of a pair of rollers and flattened into a plate; this plate is cut into pieces and shingled, i. e. one piece placed successively on top of another, until the workmen are of opinion the mass is sufficient to make a plate of such size as they wish; this is again subjected to the balling furnace a second time, until it gains the white or welding heat, after which it is passed again between the rollers, and reduced to such thickness as desired to form a plate; after which, the edges are trimmed ready for use.

Boiler plates manufactured in the above way, out of such materials, very rarely are sound, for the following reasons: scrap iron, we are well aware, previous to its reaching the rolling mill, is considerably oxydated, and many pieces highly impregnated with copper and sulphur, and occasionally a piece of steel, a put in all pile; (I believe the piling is generally done by boys 9, 10, and 12 years old;) consequently there is no safety in boilers for steamboats where a piece of steel as large as your thumb existed. To return to the effect which oxyde, copper, and sulphur would have upon the welding of iron: this subject is too well understood by scientific and practical men for me to dwell on. It will readily be inferred that boiler plates manufactured as above cannot be sound, although the edges may have every appearance to indicate it. I have seen one of these plates cut through the centre, and dis-

covered part of it to resemble a quire of paper, showing evidently that the leaves never were cemented by the welding heat; a boiler made of this description of iron must burst in a very short time, for, so soon as the oxide breaks the first leaf, the steam will rush between the different leaves, and find its way out. I am fully persuaded, that if any person would take the trouble to examine a boiler that has been bursted, they would find that the plate which gave way will be found in leaves as above described.

The second process used in manufacturing boiler plates is from what is termed half blooms: these are placed in a balling furnace, and heated, as in the process of converting scrap iron, when they are subjected to the rollers, and formed into a plate; this is cut into smaller plates and shingled, heated in the balling furnace a second time, and again subjected to the operation of the rollers, and formed into a boiler plate. The great objection to this process is, that in many instances scoria secretes itself between the different plates, and prevents them from welding in the centre, owing to the atmospheric air coming in contact with the outside surface of the mass first, consequently the weld or attachment of the particles takes place there first; the scoria existing in the centre will prevent any cohesion, and leave the boiler plate like a quire of paper, as a plate made from scraps. A steamboat boiler made of any of those two descriptions of boiler plates, is a risk, although some may stand; but it is entirely accident. My voice would be to abolish the use of either of this kind of boiler plate iron for steam engines.

The third and most superior quality of iron used for the purpose of constructing steamboat boilers is manufactured by a process very different from the two former. These boiler plates are made of what is termed the best quality mottled pig iron, which is broken in small pieces; and placed in the refinery forge, furnace or fire, and when melted is formed into what is termed a loop; it is then put under a heavy forge hammer, and formed into an anchony; this is placed in the chafery forge fire, where it receives a high white or welding heat; another heavy forge hammer is then applied to the mass, and hammered perfectly sound, and a slab formed from 12 to 20 inches long, by 8 or 9 inches wide, by 1¼ inches thick; the slab thus prepared is taken to the rolling mill, and first heated in a reverberatory furnace to what is termed a cherry red, from whence it is taken and subjected to the operations of the rollers repeatedly, until a plate is formed suitable for a boiler, and will withstand much more pressure than copper itself. This assertion is predicated on the opinion of the most experienced mechanics with whom I have had much intercourse.

I have come to the conclusion that all accidents which have occurred in steamboats, are owing entirely to a defect in the iron from which the boilers are manufactured.

To determine between boiler plates made of scrap iron or blooms, and those made of hammered slab iron, if any person having a good ear for sounds will suspend the different descriptions of plates, he will readily discover which plate is sound and that which is unsound, by striking each plate a slight blow with a common hammer; the plate which is unsound will have a jarring and irregular sound, whereas the sound or solid plate will have a clear and distinct sound; by this method it will require but a short time for a person of ordinary capacity to become a good judge of boiler plates.

My time being occupied in business, it was out of my power to arrange the above matter according to my mind, but I am well aware that there are many practical gentlemen in the Houses of Congress who will understand the

communication. Any inquiries which may grow or originate out of this, where I have not expressed myself to their satisfaction, I pledge myself to answer.

I have the honor to remain, most respectfully, sir, your most obedient, humble servant,

DAVID KIZER.

To the Hon. LOUIS M'LANE, *Sec'y U. S. Treasury.*

No. 10.

NEW YORK, *November* 28, 1831.

SIR: My attention has been attracted by an advertisement from you, in the New York Morning Courier of the 23d instant; and I have devoted some hours to an examination of the questions put therein, and to an endeavor to give answers to them, as per paper No. 1, enclosed herewith.

I beg leave to state, that I am an English civil and mechanical engineer, recently arrived in this country, seeking employ in my professional capacity; and having been among the first employed upon the construction and management of steam vessels in London, in which, from circumstances that are stated in my answers to your questions, I attained considerable experience. Having only arrived in the United States on the 8th instant, my opportunities of information are, of necessity, limited by the time; and any thing I may now state, is fairly subject to such correction as further information may render advisable; and with this preliminary remark it may be allowable to add that your questions do not appear to go far enough for the avowed purpose.

The independent paper, No. 2, has been prepared under this impression, and, it is hoped, will show perspicuously a tangible cause for the accidents which have hitherto happened among the steam craft in the United States, and why they are so much more numerous in proportion than in England. The whole of the papers are not so perfect as I could have wished; but the shortness of the time for preparing them, will be accepted as a reason why they are so.

Should my information prove of that novelty and value that I am sanguine enough to hope it may possess, this may give me a fair claim upon the Government of the United States for consideration and employ, which may appear requisite to carry the object of protecting life and property into full effect.

In this case, I would attend you at Washington, on receiving a summons to do so; it being understood that my time and expenses shall be allowed for.

I am, very respectfully,

Your obedient servant,

WM. SERRELL.

Care of Messrs. Atkins & Smith, 82 Front street, New York.

To LOUIS M'LANE, Esq.

Secretary of the Treasury of the United States, Washington.

Paper No. 1.

Qestion 1. Are you acquainted with the nature and use of steam engines?

I have been accustomed to them since 1814, and have been acquainted with them since 1800.

In what employment have you been engaged?

In that of superintendent of the first steam vessel built in London in 1815, 1816; afterwards in that of Mr. Maudslay, the engineer and machinist in London, on different occasions, and in the internal and external concerns of his establishment from 1817 to 1824; then, to 1826, in a machinery concern in the neighborhood of London, and as an engineer on my own account; and, from 1826 to 1831, (August,) in the employ of Mr. L. W. Wright, an American citizen, a native of New Hampshire, settled in London as a civil engineer and machinist.

Were you present, and in what capacity, at the bursting of any steam boiler, or the collapsing of any flue? or have you been made acquainted by any other means with the facts in any such case?

I have not been present at any such calamity, but, in 1817, my friends Messrs. Aggs and Curr, of Norwich, (England,) engineers and machinists, constructed a vessel called the "*Courier*," which was the first, and I believe the only vessel ever fitted with a regular high pressure steam engine in England. After she had run a short time, she suddenly exploded, and killed, scalded, and maimed nearly fifty people, besides entirely destroying the vessel; I was at the time cognizant of the affair through Mr. Aggs, who laid the blame upon the engine man, having heard from one of the survivors that this man had said "*he would get his steam well up, and give the vessel a grand start.*" In the same year, 1817, the vessel I had charge of was destroyed by an accidental fire, but no lives were lost, and no one was hurt; and from the boiler and engines having remained uninjured, no clear cause of fire was ascertained, and some suspicions of unfair play were excited, as the vessel was running "*conqueror*" against sailing vessels and against another steamer. Some other casualties have occurred in England among steam vessels, but not any, that I am aware of, that have arisen from bursting boilers, or that have been attended with loss of life; and all, as far as I have ever known, have been clearly traced to neglect or misconduct in the working engineer. Some petty accidents to the steam boilers of land engines came under my notice in England from 1814 to 1831, but all were obviously caused by neglect of the working engineer, and do not apply to the present inquiry; and I have not been long enough in the United States to become acquainted with any affair of this sort, except by newspaper report.

Question 2 is not stated or answered, as my observations do not include any thing connected with the terms of the question.

3. If the boiler contained a flue, what was the difference between the height of its upper side and that of the lower gauge cock?

All the English boilers I have ever seen, have from six to ten inches between the top of the flue and the lower gauge cock, and about six inches more to the upper cock.

4. What was the weight, per square inch, upon the safety-valve?

Until within a few years, no English vessel had more than 7 lbs. pressure of steam, and very many not more than 5 lbs. More recently, some have been fitted upon the expansion principle, working as high as 40 lbs.; reduced

by expansion to about 4 lbs. at the condenser; but no one, that I know of, went beyond that, as in fact the English engineers consider a greater pressure an uncertain, and, therefore, an unmanageable power, as being liable to rise very suddenly much higher, and then drop again.

5, 6, 7. Not answered, for same reasons as No. 2.

8. In what part was the boiler rent? and what was the appearance and extent of the rent?

In the case of the "*Courier*" (See No. 2,) the cylindrical boiler had separated nearly in the middle, the ends flew in opposite directions clearing all before them, and the edges of the rent were jagged and irregular.

9. When the bursting happened, was the boat under way or at rest? was the valve open? If so, how long before the accident was it opened by the engineer or by pressure?

In the case of the "*Courier*" the boat was at rest, but on the point of starting. It was believed that the valve was ignorantly shut and fastened by the engine men immediately before the accident, but it was meant to have been opened by pressure.

10 and 11. Not answered, for the same reasons as apply to Nos. 2, 5, 6, and 7.

12. Do the iron boilers used in the western waters usually accumulate a calcareous incrustation at the bottom? If so, have any, and what, means been used with success to prevent it?

13. When a sediment is so formed in the bottom of the boiler, does it require more fire to raise the steam? How often is the sediment removed, and by what means?

14. Are any means used for preventing incrustation on the bottoms of boilers? If so, what effect has been observed?

I am not acquainted with the course of these matters in the western waters. In England, the river vessels accumulate mud, and the sea vessels salt, if means are not taken to check it. In the English boilers, the flues are laid through the water, with about four to six inches of water below both the bottoms of the flues and the ash-pits. Into this lower space, all the grosser matters of mud and sand, and salt, fall by their own gravity; and in the best engines it is pumped out by a pump which has two parts, one drawing out the foul matter through an exterior pipe, and the other part of the pump injecting fresh water. (See answer to question 17,) upon the crowns of the flues by a smaller pipe which passes through the eduction pipe connected to the pump, which draws out the foul matter. By this means, the best engines employed in the Thames, and thence to sea, have many of them run in the sea and river way for a month; and then, on being opened and cleared, an eighty horse boiler would rarely have so much as two bushels of salt and mud residuum below the flues and ash-pits.

15. What means are adopted to prove steam boilers? What pressure to iron of a given thickness? Are the proofs made hot or cold?

I am not acquainted with the way of doing this in the United States. In England, when it is wished to prove a boiler, a common hydraulic plunger is used; the boiler being filled with cold water, and all openings secured, the plunger is loaded generally to double the pressure intended to be worked hot. I have never seen any necessity to carry this proof over 14 lbs. on the inch in common condensing boat boilers in England.

16. Is any instrument used to show the temperature of the steam or boiler above the water? If so, what is it?

I am not aware of any instrument being used in England for this specific

purpose, but no doubt the common Fahrenheit thermometer would indicate these differences, if desirable to know them.

17. What means are used to prevent the fire, from the fire place and flue, from extending to the boat?

In England, the several fire places, flues, and ash-pits of boat boilers, are all surrounded with water, except just the feeding doors, and, in front, below; and, above these, the vessel is lined with sheet iron; and where the chimney (always single in England) comes out of the boiler, a cylinder is fitted on the boiler so as to encircle the chimney. In the ring formed between this jacket, as it is termed, and the chimney tube, a body of water is kept in circulation, being thrown in by a pump, which takes off a portion of water from the condenser, and then this water is drawn out and sent into the boiler to keep up the supply of water by the pump described in the answer to questions 12, 13, 14, so that fire cannot by any means get at wood from these flues, except by passing through water.

18. Not answered; my practice or knowledge in ship engines not coming within the question.

19. Is met by answer to question 17.

20. Not answered; my knowledge being comprised in my answer to the question No. 1.

21. Not answered; no observation on this question having come within my practice in boat engines.

22. }
23. } Are answered at length in paper No. 2.

The above respectfully submitted by,
Your obedient servant,
WM. SERRELL,
Civil and Mechanical Engineer.
Care of Messrs. Atkins & Smith, 82 *Front street, New York.*

To Louis McLane, Esq., *Secretary of the Treasury of the United States, Washington.*

Paper No. 2.

New York, *November* 28, 1831.

In inquiring into the causes of the many accidents which appear to have happened by the bursting of boilers on board steam vessels in the United States, I have not heard of any experimental trials to prove the strength of metals, and the relative effects on different positions and lengths. I am, therefore, obliged to have recourse to my own information and experience.

In 1822, I was a party to a set of experiments on iron and other metal bolts, the results of which were, that an iron bolt of best metal, one inch diameter, four feet long, bore a strain of twelve tons, or 26,880 lbs., without any visible alteration.

Assuming this as a basis, it will be found that a one inch square bar will bear about 34,200 lbs.; and that a bar of one inch by half inch will bear 17,100 lbs. The bolt in question broke with 17½ tons, or 40,200 lbs.; and, upon the same proportions, the square iron would have required about 47,300 lbs. to break it; and a bar of one inch by half inch would require about 17,650 lbs. to break it. Let us apply these data to a tubular steam-

boiler, such as I understand are used in the western waters, and assume it to be twenty feet long, and two feet diameter inside, made of half inch thick iron plate, and it will be found that the pressure tending to rend or split the boiler in the transverse or circular way, will stand thus:

Diameter 24 inches + 3.1416 = 75.3984, say 74.4 inches in circumference nearly. Then, if the pressure of the steam within the boiler be 40 lbs. on the inch, the power exerted tending to break the iron hoop will be 3,016 lbs., or about one-eighth of the power required to break it.

The length of the boiler being taken as 20 feet, will be 240 inches + by 40, the steam pressure in lbs. will be 9,600 lbs. or about $\frac{10}{24}$ of the power required to break it lengthwise.

But, if this power of steam be increased to 100 lbs. on the inch, as I am informed is frequently the case, the total power of steam tending to rend the two ends of the boiler apart becomes 24,000 lbs., which goes immediately beyond the breaking point of 23,650 lbs.

Herein, I submit, lies the secret of all the explosions which, as far as I have heard, are universally characterized one way, namely, that one or both of the ends of the boiler flies out of their seat longitudinally like rockets, clearing every thing before them, and scattering destruction or injury on every thing within their course.

The risk of making laws on such a subject, is, that the law may make against improvements; and this consideration has deterred the British Government from passing any act relative to steam engines in vessels: but, in the United States, the evil appears of a magnitude requiring the interference of Congress, which perhaps would find it the safest way to affix a penalty upon the owners, commander, and engineer, of any steam vessel working a greater pressure than 60 lbs. on the inch in a boiler of 20 feet long, made of half inch iron plate, and in other boilers in like and due proportion.

The above respectfully submitted by,

Your obedient servant,

WM. SERRELL,

Civil and Mechanical Engineer.

To Louis McLane, Esq., *Secretary of the Treasury of the United States, Washington.*

No. 11.

Cincinnati, *December* 28, 1831.

Sir: I have been deterred from sending you the result of ten years' experience and observation on the subject of steam navigation, by the hope of obtaining an united expression from all the owners and masters of steamboats in this city.

After several meetings, attended by a great diversity of opinions, our efforts died away by common consent. Being anxious myself to prevent the passage of laws which might increase the embarrassments of the subject, I have determined, even at this late period, to give you my views in a *very few words*; for I am under the impression that some of the communications you have probably received, are better calculated to throw *obscurity* than *light* upon it.

With regard to the *explosion* of steam boilers, it is reduced to a certainty here, that nine-tenths, if not ninety-nine-hundredths of these accidents are occasioned by the neglect of the engineer, particularly in letting the water get too low in his boilers. We believe that any tolerable boiler will bear all the pressure that we have any use for, so long as it is kept clean, and is well supplied with water.

As it is evident that these circumstances are entirely dependant on the engineer, common sense would dictate that the care and responsibility of this matter should be thrown on him, and this can only be done (as I conceive) by some mode of examination and license, which might well be extended to *boats, boilers, masters,* and *pilots,* as well as engineers, *annually,* all being involved in the security of *lives* and *property.*

But, sir, there is another hazard in the western navigation, not particularly alluded to in your notice, yet here considered of more importance than the risk of steam; it is the danger of boats coming in contact in the night. This difficulty increases as boats are multiplied, and the navigators of the west have long racked their invention for a remedy.

Human prudence cannot counteract the deceptive appearance of distant lights; nor can human wisdom devise a rule which will apply to all the circumstances of our western rivers, so as to determine on which side of each other boats shall pass. The consequence is, that so long as boats continue to run in opposite directions at night, they will be liable to that most alarming of all occurrences in steam navigation. The amount of lives and property lost in this way already exceeds the amount by explosions.

Now, in my humble opinion, the only possible remedy for this growing evil, is to prevent every description of *boat, craft,* or *raft,* from *descending* our waters at night. This will leave the rivers free to the boats ascending, and it is safer to ascend than to descend at night, on account of other obstacles. This regulation would equalize the voyages down and up, would be more pleasant to passengers, and save a vast amount of lives and property. I think no prudent man, who knows the western rivers, will say that Providence ever designed them to be descended by vessels of six or seven hundred tons, at the rate of 18 or 20 miles an hour, in the night.

I have been in the command of steamboats for the last six years, and for my standing, &c. &c., I refer you to his excellency Governor Cass, now in the War Department.

Very respectfully, yours,
ROBT. WALLACE.

Honorable Louis McLane, Esq.

No. 12.

Newbern, N. C. *January* 4, 1832.

Sir: It was but lately that my attention was called to your circular containing "interrogatories in relation to the bursting of steam boilers," or I should, ere now, have thrown my mite of experience into the common stock, for the preservation of my fellow citizens. I am no steam engineer by profession, but, during seventeen years past, I have owned and built four steam saw-mills in this place, and acted as engineer and superintendent over the same. I have always worked on the high pressure principle, and have sel-

dom used less than 120 lbs. to the square inch, frequently between that and 150 lbs., and when the engine has been out of order, have exceeded that gague. When I rebuilt what is now called the "old mill," after the former one had been burnt down, I tried the boilers, which had been exposed to the fire, with 250 lbs. to the square inch. The engines I have used have all rated about 36 horse power. The cylinders 12 inch bore, 2 feet 2 inches stroke —3 cylinder boilers 21 feet long by 31 inches, without any flue, and the fire consequently made under the boilers.

I have made it an uniform practice of cleaning out my boilers, and examining the connexion every third Monday, but immediately after a gale, when the water becomes salt, or while heavy freshets cause it to be muddy, they are cleaned out every week; when a man goes into the boilers, and with a mill-peck, or small hammer, removes the crust, (if any there be) which collects on the side and bottom, and, at the same time, examines and cleans out the connexions to prevent any impediment to an equal and plentiful supply of water in all the boilers. With all my care on this head, I have three or four times been compelled to stop the engine on account of the connexion being obstructed. Once, the matter had become so hard that it could only be removed by the cold chisel. During a spell of sickness to which I was subjected, the man to whose care I had entrusted the engine neglected to clean out the boilers, and the consequence was, that the middle boiler burst, occasioning, however, no other damage than what was done to the boiler. At the time of bursting, we were under a pressure of about 135 lbs. to the inch, with a full head of water. After the accident, I examined the boilers minutely, and found that on the five front sheets of each boiler, a sediment had collected to the average thickness of half an inch—that the fourth sheet from the front of the middle boiler was rent across lengthways with the boiler; that all the other sheets, where this non-conductor had formed, had bulged out considerably, as if they were ready to burst.

The boilers I have in use at present are 17 years old, and have been in constant use for 12 years, under daily and heavy pressure. They are, therefore, getting corroded and thin in various places, and we have had what many would call (and, with differently constructed boilers, would no doubt have proven fatal) bursting of boilers more than once of late, but all the injury sustained, has been the trouble and detention of patching the damaged place.

The length of time the present boilers have been in use, the powers they have constantly been exposed to, and the effect produced by the accidents to which they have been subjected while in use, have convinced me of the superiority of cylinder boilers of the above dimensions, and without a flue, to those now in use on board most of our steamboats, which are constructed with a flue, generally placed so near the bottom of the boilers that the space left, being so obstructed with stays, it must be next to an impossibility effectually to remove the sediment which collects there. We have at present an example in this town which goes far to strengthen me in this opinion. I allude to a boiler constructed with a flue, recently taken out of the tow-boat attached to the dredging-boat employed to remove obstructions on the swash. This boiler is about two and a half years old, but has not been in constant emyloyment to exceed twelve months, and never under a pressure to exceed 75 lbs. to the square inch; but, owing to the impossibility of cleaning it out, and removing the sediments from the bottom, has become

totally useless even in that short time; and I venture but little in saying that nothing but the size of the boiler, (30 inch, with 15 inch flue) has prevented an explosion. I must acknowledge myself not sufficiently acquainted with condensing engines, to judge of the objections which may be started against the use of such boilers as above described. If, however, it be objected that a sufficient quantity of steam could not be generated,—by making the sheets a size thicker, the boilers might be made six inches larger without injuring their strength, and additional boilers might supply the deficiency; and, besides, where is the passenger that would not gladly exchange a little speed for a good deal of safety?* The additional firewood which such boilers would consume, can hardly be considered an object, when compared with the number of lives and amount of property at stake.

I have often reflected that the constant employment, night and day, in which most boats are kept, makes it next to impossible for the engineer to pay that attention to the inside of the boilers (were they even constructed so as to admit of this care,) which safety requires. Should this be found to be the case, a law compelling every boat to lay by, say 24 hours in the week, for the especial purpose of cleaning out the boilers, and examining the connexion, would prove of salutary effect.

My object in publishing this letter, is to elicit the opinion on this subject of some more able and experienced engineer, if any such should feel it worthy his attention, as the truth is the only object of

Your obedient servant,

F. NAESTED.

To the Hon. Louis McLane,
Secretary of the Treasury.

No. 13.

U. S. Navy Yard, Gosport, Va.,
November 23, 1831.

Sir: I have noticed several times your queries relative to steam boilers, and have thought that, as I have had a little experience in steam, I would give you a few thoughts on the subject. In the year 1810, I think it was, I was employed to build the steamboat Delaware, and visited New York for the purpose of examining the boats then running on the North river, and heard a good deal about bursting of boilers. After the Delaware was completed, I began to think about steam, and planned a boat with wheels to work on the inside. This boat I obtained a patent for; she was called the Eagle, and run from Bordentown to Philadelphia, in opposition to the steamboat Phœnix, the first that run on the Delaware, except that built by Mr. Fitch many years before. But I can tell you nothing about that: it was before my time.

I remember that, in coming down the river, between Five Mile point and Philadelphia, the boiler of the Eagle collapsed: we were then ahead of the Phœnix. The cause of the boiler collapsing, was ascribed by the engi-

* I have thought that a law regulating the speed of steamboats, so as not to exceed a given number of miles per hour, or a given time in which the boat should arrive at its destination, after it left the place of departure, would be of service.

neer to the steam having all been run off, and a vacuum being formed in the boiler. I examined it myself, and found that the flue had collapsed between the iron braces, which caused the boiler to leak. However, no damage was done to any person on board. Since 1814, I have had nothing to do with steamboats, except to travel in them, and I should always have slept sounder if there had been the security which I am about to recommend. To make steam boilers so strong that no accident shall happen for want of attention, is impracticable.

The plan which I would propose, is, that the boiler and machinery should be so separated by strong and tight bulk-heads from the cabin, that, in the case of the boiler's bursting, no one would be injured but those whose business it is to attend to it. This can best be effected during the building of the vessel. Those bulk-heads should extend from the bottom of the vessel to the top of the awning deck: from there it should be so constructed to form a passage for the steam similar to the pipe now placed at the safety-valve, only much larger: the doors to the entrance of the boiler room, should be hung from the inside, made very strong, and perfectly tight when shut, (on the principle of a valve;) there should be air ports in the side of the vessel for light and air into the boiler room; then, in case the boiler should burst, the doors would shut, the steam would escape out at the air ports, and the passage in the top of the boiler room, which should be carried as high as the smoke pipe, in the form of a cupola. Where the boilers are placed on the deck or wheel guards, this plan could also be adopted.

It has long been impressed on my mind, that Government should legislate on this subject, and have been more confirmed in the utility of my project, by the bursting of the boiler of the steamboat Potomac, which runs between Norfolk and Washington. In that case, none of the passengers were injured, which may be attributed to the door which led into the boiler and cook room being shut. One of the servants in the forward cabin hearing a noise in that part of the vessel, opened the door that led into the boiler room, and was instantly killed by the steam, which would not have been the case if he had not looked in. You will therefore perceive that, by strong bulk-heads, many lives would be saved—I do not say all, but there would be but few when compared to the many lives that have been lost under the present mode of constructing steamboats. I think that I am correct as to the Potomac; but, as that boat runs in your immediate vicinity, you could, no doubt, get a more correct statement of the occurrence.

I am, sir, very respectfully,

Your obedient servant,

FRANCIS GRICE.

Honorable Louis McLane,
Secretary of the Treasury, Washington.

No. 14.

New York, *7th December*, 1831.

Dear Sir: The Directors of "The New York and Boston Steamboat Company" have received your circular, dated 21st November ultimo, covering one from the Treasury Department, dated 12th October last, embracing

sundry inquiries touching accidents by explosion of steam boilers on board steamboats, and also having a tabular form to be filled up as directed therein.

These documents have been handed over to me to reply to, and, in accordance, I beg to return you the same with such observations as I deem of *practical utility*, in furtherance of the humane views of the resolution of Congress of 4th May, 1830, which the honorable Secretary of the Treasury is desirous to carry into effect.

I lay no claims whatever to a scientific knowledge of the subject in question, and, if I did, I would but find myself at variance with as many who arrive at different conclusions, as those I might accord with. Science has done much in preventing, but, as yet, has not effected an entire prevention of explosions. And so long as this powerful agent (steam) is applied, as now applied, to control rapidity of motion beyond all former precedent, a liability to accident must exist; for the constant and unremitted care and *perfect knowledge* of the engineer, which may be required to prevent accident, cannot always be counted on or controlled; and the same remark that would apply to a powder house or a stage coach, applies to a steamboat—*accidents may occur*, and the most that can be done, till experience teaches us that an explosion is impossible, is to guard against its destructive consequences when it does ocur.

With this view of the subject, then, I would respectfully suggest a few observations which may illustrate my views.

I have noted that by far the greatest number of accidents by explosion and collapsing of boilers and flues, I might say seven-tenths, have occurred either whilst the boat was at rest, and immediately on starting, particularly after temporary stoppages to take in or land passengers. These accidents may occur from directly opposite causes, either by *not letting off enough steam, or by letting off too much:* the latter is by far the most destructive.

You will readily perceive, that, with the usual powerful fires employed when the engine is stopped, and thus ceases to "work off" the rapidly generated steam, that, unless the escape valves are opened, the boilers must give way; but explosions from this cause, though at times disastrous, are not always so, for a slight rent gives immediate relief. A boiler seldom explodes when the boat is well under weigh, as the engine works off steam as fast as generated; but if the steam is suffered to "blow off" when the boat temporarily stops, and for too long a period, which is sometimes the case, by the inexperience of the engineer, and an unexpected delay of the boat—the fires kept up and the engine *still*, and consequently no supply of water to the boilers, it is evident the contents of the boiler must be soon exhausted; in addition to which, the *careening* of the boat by the passengers, aids in exposing the metal of the boiler, which, with its diminished contents, is rendered totally unsafe for the reception of a new supply of water. The consequence is, the moment the engine is put in motion, the water thrown into the boiler is converted into steam with the explosive power of gunpowder, *and as instantaneous*, and the boiler and its flues must be very strong to resist it. This will occur also from a *careening* of the boat with two boilers on board, whilst stopping to land or receive passengers, as before mentioned. The boat returning to its level, returns the diminished contents of the boiler thus most exposed to the action of the fire, and an explosion occurs.

An explosion from the foregoing causes, is difficult to guard against. The most experienced engineer may be deceived by his gauge cocks; for, as the contents of a boiler approaches its minimum with a powerful fire, it is

lifted as it were from the heated metal, and is neither water nor steam, but partaking of both. His water gauge cock may give evidence this minute of *water*, and the next instant may be *steam*; he continues the *blowing off* his steam in honest security, and with the additional motive of securing his reputation for precaution; and when he hears the bell ring, he closes his valves, and the first jet of water in the boiler, leaves a multitude to wonder at the cause of an explosion after *so much precaution.*

Accidents also occur by making up the fires too rapidly. These are generally confined to the steam chimney, occasioned by too sudden an expansion by heat, of the plates of metal, causing them to tear out near where they are joined or lapped over, that immediate part not being so readily heated as the parts contiguous.

In fact, when it is considered how many causes may be assigned, embracing the wide range of competition in speed, neglect of engineer and firemen, imperfect metal, &c. &c., I come irresistibly to the conclusion, that, though *care and skill* has done much, and may do more toward preventing accidents of this nature, yet accidents are likely to recur, and the wisest course is to devise some plan to preserve life at least, till experience and practice develop a certain remedy against explosion of boilers. With this view, I proceed to offer a cheap and practical safeguard.

1st. No steamboat should be allowed to locate a boiler *under deck*, as, in the event of explosion, the passengers can't well escape injury, and the boat is also liable to destruction.

2d. The safest location of the boilers is on the wings of the boat, one on each side, and over the water. Most of the large boats are now so arranged; but, to guard against injury to passengers, a strong bulk-head of thick oak plank, well braced with iron, should be erected, commencing abaft the boilers, and running forward of them, terminating at top with a curve outward, the 1-4 or 1-8 of an inch; strong beams of oak or bars of iron to be placed at top of these bulk-heads, and crossing the boat, thus effectually resisting a pressure from without: *inward*, all the wood work on the outside of the boilers to be slight, and so arranged as easily to yield to an explosion of the boiler. The communication from the deck to the boiler room to be by doors opening inward, the doors being strongly made, and larger than the door way. Thus, the deck is entirely shut off from the boilers, and, in the event of an explosion, the extent of injury to the passengers would be perhaps a little spray of hot water and ashes that might find its way back upon the deck; but it would be almost impossible that any serious injury to them could occur. As to the engineer and firemen who might, at the time of an explosion, be in the boiler room, it would be difficult to arrange entire security for them; for, after all, they would be likely to neglect availing of it, and it is their exclusive business to look out and guard against explosion. The fuel room would be within the bulk-head; and a cross partition bulk-head, with doors opening inward, would preserve them if they chose to avail of it, so that only one person at a time, or, to the extent, 2 persons, need be exposed.

The only precautions to be used by the passengers who would desire to be safe, would be, to bear in mind that the periods most likely for an explosion to occur, are—

1st. When a boat is getting up its steam to start;
2d. Immediately on starting;
3d. When stopping to land and receive passengers; and,
4th. And most particularly, on starting from a temporary stoppage.

At these periods, let them keep below deck, or as remote from the boilers as they chuse.

And I humbly conceive, with boats arranged as above stated, and with these precautions, passengers may live to *speak* of explosions and collapses as they would of losing a spar or a sail at sea, or the breaking of a carriage spring on which they were travelling.

For, let the scientific mystify and puzzle themselves and others as they will about safety-valves and square inches, steam gas, pressure of atmosphere, and the difference between an explosion and collapse, it is enough to know that these accidents are likely to occur; and more likely, when it is insisted on by the travelling world that a boat going 10 and 12 miles the hour, is preferable to one going but 5 or 6. And therefore, until it is clearly proven, by long experience, that a boiler wont burst, nor a flue collapse, I think there is wisdom in guarding, *ad interim*, against their destructive consequences.

If you deem there is any thing contained above of practical utility, you are at liberty to hand this, with the return, to the Secretary of the Treasury, excusing the haste in which it is written.

I am, very truly, your obedient servant,

CH. AUG. DAVIS,

One of the Directors, and President pro tem. of the New York and Boston Steamboat Company.

To Samuel Swartwout, Esq.
Collector City N. York, &c.

No. 15.

Clinton, Mississippi, *November* 20, 1831.

Sir: To your interrogatories in relation to the bursting of steam boilers, I take leave to reply. I am not an engineer, and have had no employment in the conduct of steam machinery, but, from a long acquaintance by traveling up and down the Mississippi, with attentive observation, facts have come to my knowledge which may serve to establish and to explain the real causes which have led to the numerous disasters experienced in steam navigation. In all cases of explosion, the water in the boiler has been below the gauge cocks.

In boats propelled by high steam (the most common on the western waters,) the weight per square inch, or the capacity of the boiler, is from sixty to one hundred and twelve pounds. In low pressure engines, the weight, I think, is never more than twenty pounds.

The boiler is rent always either at the head or collapsed in the flues. The boat on which I had the misfortune to be, when her boilers exploded, was the Helen McGregor, at Memphis. She was leaving the shore slowly, waiting the departure of a gentleman named Reed; the detention was about ten minutes after the steam was sufficiently high, and, during that period, no steam escaped by the safety-valve. We had been at Memphis about one hour, and the fires had only been partially suppressed. I am of opinion that the head of the boiler, which flew out, was cracked about four inches from the upper edge. A part of the head passed upwards, destroying the front of the hurricane deck, and killing several persons in its range. The

piece weighed upwards of one hundred and fifty pounds, and lodged about sixty feet on the top of the hurricane deck from the head of the boiler. The steam and hot water from the six large boilers, rushed through the connection pipes, and escaped in a few seconds. The outside boiler on the starboard side of the boat was the one which burst. Its head flew out towards the stern, and the boiler itself was hurled, with immense force, through the bow of the boat, passing exactly at deep water mark.

The fireman had begged the engineer to suffer the steam to escape—I do not assert this to be true, but believe it to be so, having heard a poor fellow, who escaped with a wound, say so just after the explosion. I have never seen the upper part of boilers heated red hot, but I have no doubt it often takes place, and always in cases of explosion. I do not believe that any steam boiler ever burst when regularly supplied with water from the supply pump. It sometimes happens a boat will stop to wood with a heavy head of steam, and, being in a hurry, fail to suppress the fires, or escape the steam; every thing is inactive until the bell rings to start. At this moment, there is danger: the contact of the cold water from the supply pump, which is thrown into the boiler, with the gaseous quality of the steam, produces an expansion incredible and instantaneous.

I passed up the Ohio in the steamboat '76; she had her boilers cracked in the head, and clamped with wrought iron. On board of a steamboat called the Industry, the supply pump was out of order, and for three or four days we were obliged to supply the boilers by hand, and as soon as the water had evaporated into steam, stop the boat, and pump the boilers full again.

To the twentieth interrogatory, I have to say that about thirty persons were scalded to death by the steam and water on the Helen McGregor steamer. Many others were wounded, and slightly scalded. I am of opinion that the steam is harmless at the distance of fifty feet, but fragments of the explosion are dangerous more than three times that distance. The current of steam from the boiler was instantaneous, but prolonged for a few seconds, perhaps five or six, from the report of the explosion, which was about as loud as a six-pounder.

To the twenty-second interrogatory, I have to state that, in all cases within my knowledge, the explosion has taken place at the head of the boilers, and caused by the neglect of the engineer; and I am convinced that boilers of a cylindrical form, reduced in diameter, with wrought iron heads, would greatly tend to diminish the chances of explosion.

I am, sir, your obedient servant,

A PASSENGER IN THE H. McGREGOR.

Louis McLane, Esq. *Secretary of the Treasury.*

No. 16.

Washington, 21*st April*, 1832.

Sir: I have examined the papers handed me relating to the explosion of steam boilers. I find in the letters of Mr. Bakewell and Mr. Redfield, the latter particularly, many sensible and rational remarks, and which meet my entire views on the subject. Mr. Redfield's remarks, in the tenth page of his communication, are doubtless correct. If Congress would inquire into

the loss of human life by drowning, &c., from vessels navigated within her territory, since the twentieth of June, 1816, the date of the first explosion, to this time, it will probably far exceed the number lost by the explosions of steam boilers, which has been, in that period, two hundred and sixty-three, caused by fifty-two explosions, and the comparative number of passengers on steamboats, since that date, must exceed those on all other crafts by at least three to one.

I have, therefore, come to the conclusion, that no other legislative interference can be beneficially applied, but an inspection to test the strength of boilers by hydraulic pressure, making it necessary that the boiler shall be put to three times the pressure, under the hydraulic pump, than it is allowed to carry in steam.

I beg leave to suggest, that, if it comes within the power of Congress, it is important to pass an act to regulate steamboats meeting in the night. I have witnessed four fatal accidents of this description, in all of which lives were lost, and heavy losses sustained by all the boats—two of the boats under my command, and two on board of which I was passenger—consequently, I have thought much on the remedy to be applied. The one on which I have determined as the most simple, and the most effectual, is to compel the boat bound down stream to stop her engine, and drift in the stream when she has approached within half a mile of a boat bound up stream. I would explain this by stating, that, if the descending boat is floating, the ascending boat heads, or steers clear of her, and cannot come in contact with her. The time lost will, in no case, exceed five minutes, as a boat bound up, making but six miles an hour, must make half a mile in five minutes; besides, the boat drifting in the stream brings her some two minutes short even of that time. The penalty imposed might be, to make the descending boat liable for all damage if she did not stop her engine in time, and in case of the descending boat stopping her engine in time, and at the proper distance above; and if the ascending boat then runs into the descending boat, make the ascending boat, in like manner, liable for all damages. All boats descending the river should be prohibited from passing down the narrow and short channels of the Mississippi river, which is attended with great danger in case of boats meeting in those chutes. Some losses have occurred in that way.

Another subject of importance, permit me to suggest: in all the waters of the United States, steamboat owners are in the habit of running boats that are worn out and rotten. If Congress will make provisions to appoint the necessary officers to inspect them, it will be a beneficial arrangement, particularly to the western States.

I am, sir, very respectfully,
Your obediant servant,
HENRY M. SHREVE.

Hon. C. A. Wickliffe, *Washington, D. C.*

No. 17.

Boston, 15*th November*, 1830.

Having never been on board a steamboat at the time of a boiler's exploding, nor witnessed the explosion of a steam boiler in any other situation, I

am not able to give you much, if any, information in answer to your inquiries, as requested in your circular of the 1st of August last, or at least none which can be regularly classed in the list of interrogatories. Yet as my experience in the use of steam in various ways and for different purposes, has brought to my mind and notice certain facts relating thereto, and, among them, some which I have never seen noticed in any writings on the subject I have concluded to communicate them to you, leaving it to your discretion to make such use of them as you may think proper.

My first experience in steam engines commenced in 1814, in the city of Baltimore, where I was employed by Capt. George Stiles in the manufacturing of the rotary steam engines, which were operated by high steam of great elasticity, being at times from 150 lbs. to 200 lbs. per inch pressure. The boilers or generators were of different metals and forms, being of copper, of wrought iron, and of composition metal pipes. During the time I was there, no accident, even of burning or overheating a generator or boiler, occurred.

Since my leaving Baltimore, I have been employed in New York, North Carolina, and this city, in the building and operating of engines of both high and low pressure, and have repaired many boilers in steamboats which had been overheated, but had not exploded. The steamboat Eagle, of Boston, owned and commanded by Capt. John Wood, having a low pressure or condensing engine, with two cylinder wrought iron boilers, with cast iron heads, without flues, 2 feet 6 inches in diameter, and 24 feet in length each, set in brick work, had her boilers very much injured in the bottoms or under sides. The injury was attributed to negligence in not keeping them clean, a quantity of sediment having collected in the boilers, and settled at the bottom, and formed an incrustation of from 2 to 3 inches in thickness, which was in some places so hard as to require a hammer and chisel to disengage it from the bottom of the boilers. The metals, for nearly the length of the boilers, was, in consequence, so much injured that it became necessary to repair the bottoms with new irons, and to change them, making the parts which were before the under sides, the tops or upper sides, by rolling them in their beds. This damage was sustained in the course of two or three weeks after the boilers were set or put in operation. Whether any explosion would have occurred is uncertain, as the boilers were discovered to leak immediately over the fire in the furnace, and the discharge from those places extinguished the fire.

A steamboat with a low pressure engine, called the Massachusetts, of this port, having two cylinder copper boilers, with return flues, was injured by suffering the water to get too low, whereby the flues were uncovered: they were in consequence condemned and taken out. On examination of them, I found the flues, the inner shells, flattened *directly underneath* the *safety valves*, but, in every other part, the form was retained. And the query has occurred to me, whether the opening of the safety-valve, and shutting it suddenly, may not cause a reaction in the boilers, upon the principle of the hydraulic ram, and thus occasion explosion. The metal, however, was so much injured by the heat as to become hard, flinty, and brittle, losing all its tenacity and maleabillity, and was supposed by experienced coppersmiths, to be gun metal. I have, also, observed that wrought iron, in similar cases, undergoes a change, whereby it becomes like cast iron. The boilers being taken out, two others of wrought iron, of a cylinder form, with cylinder flues, were put in, and the boat put in operation. From the incrustation formed

between the flues and boiler shells or outer coats, and by letting the water get low, these boilers were injured and condemned, also, although they were used but about three weeks.

The steamboat Legislator, (a boat which had a boiler explode in the harbor of New York, by which several persons were injured) plying between this port and Bath, in the State of Maine, having a low pressure or condensing engine, overheated her boiler in consequence of the forcing pump being out of order, whereby the water was not kept up. The oval or elliptical furnace flue was much flattened on the upper part, but before any explosion took place, the fire was extinguished, and the boiler got cool before water was forced in, or the boiler filled. I was informed by the agent, who was on board at the time, that the *upper part* of the shell or outer coat of the boiler, was afterwards discovered to have been heated to so great a degree as to burn a woollen jacket, which was lying on it. I am of opinion that, had the forcing pump been put in operation prior to cooling the boiler, the liability to an explosion would have been great. I afterwards repaired the boiler, and discovered the iron to be hard and brittle in those parts where it was much exposed to the heat.

As these are the only instances of extraordinary injuries to boilers, which have come within my observation, you will perceive my information is very limited as to the subjects of your inquiry. My opinion is, that in every one of these cases, the injury might probably not have occurred had a proper degree of attention been paid by those entrusted with the management of the machinery; at least, the injury did not arise from any defect of the materials.

Presuming that much of the information which will be derived, as to the causes of explosions of steamboilers, will be matter of opinion, I will take the liberty of stating what has appeared to me as having been the cause of many of the explosions in the boilers on board of steamboats in the waters of the United States: and, first, to want of skill may be fairly attributed many of the accidents which have happened, whether attended with explosions or not. The introduction of steam navigation has been so rapid, that men of character, capability, intelligence, skill, and sobriety, were difficult to be procured in sufficient numbers, and such, when employed, demanded liberal compensation for their services. The several owners, competitors, in the various lines or routes, governed by a mistaken policy, rather than pay the wages demanded by competent and skilful engineers, have, in many cases, employed those as engineers whose whole knowledge consisted in understanding how to stop and start an engine, and, as firemen, those whose only qualification was, that they could throw wood into the furnace. Hence, when any part of the machinery happened to be disordered, those entrusted with its management, being conscious of their want of science and skill, became incapable of applying even the limited knowledge which they possessed, and injury and accidents ensued. Again: engineers and fireman on board of steamboats have been not unfrequently in times past, and I believe they are in some cases at present, treated with intoxicating liquors by the passengers, and thereby rendered incompetent to manage the machinery.

What plan the Government can devise to prevent injuries, arising from this last named cause, I cannot judge, but it has appeared to me that a board of engineers might be formed in one or more of the ports of the United States, authorized to examine the working engineers and firemen of steamboats, and to grant to those found competent, as to skill, on their producing

certificates of regular habits satisfactory to the board, a diploma or certificate, (renewable yearly, on producing certificates from their employers of continuation in good conduct.) Such engineers and firemen would thereby be able to command good wages; the owners of steamboats would eventually prefer to employ such men, as their property would be less liable to be injured, and boats having such men would be preferred by passengers on account of the less liability to accidents. The calling of an engineer or fireman would in consequence become one of more respectability, and young men of competent qualifications would be thereby induced to embark in it. For, whether the boilers explode in consequence of want of water, producing hydrogen, or by being overheated for want of a supply of water, or by overstraining them by excess of steam, or from whatever cause the explosion or injury may arise, I am of opinion that, in very many cases, these disasters may be traced to incompetency, intemperance, inattention, or rashness, as the first cause. Laws compelling the manufacturer of engines to build boilers of particular forms and descriptions, of certain materials, &c. will be, in my opinion, inadequate to remedy the evil. The manufacturer is already induced, from the number of competitors, not only to do the work well, to adopt the most judicious plan and form, but likewise to select the best materials for the boiler and engine. But since, however good the boiler may be, it is subject to be exploded in twenty-four hours as well as in as many weeks or months, it follows, at any rate, that some plan to secure safety to the passengers, other than a mere regulation respecting the building of them, must be adopted. Manufacturers, for instance, may be compelled by law to make the boilers of steam vessels capable of sustaining a certain pressure per inch, yet boilers which have been tried and found capable of sustaining such a pressure may, after being operated a day or two, become, through inattention or incompetency in the management of them, incapable of sustaining with safety one half of the standard pressure. What then can be the security to the public by adopting such a course? Surely none. The only way, in my opinion, to remedy the evil, is to devise some means to ensure that the machinery in steam vessels will be managed by skilful and temperate engineers and firemen. A regulation of this sort being once put in operation, it would follow, of course, that no boat having an insufficient boiler would be run, for an engineer would not risk his character to favor either the owner or manufacturer.

It may be necessary, likewise, for the Government to require from the captains or owners of such vessels some proof (to be exhibited to the collector, or other officer of the port) that the engineers and firemen employed on board their boats have been examined and approved by the board; and, in case the collector shall find that such is not the case, he may detain such vessels until they are furnished with such engineers and firemen. That such a plan will require sometime to mature, I am sensible, yet, by having it go into operation at some future day, the owners of boats, engineers, firemen, and manufacturers of engines, &c., will be ready to meet it, and, in the meantime, the public safety will be gradually increasing as the time for examination approaches.

I have, sir, thus far endeavored to meet your wishes, and although the plan I have adopted may be considered not in strict conformity to the views of the committee appointed by the House of Representatives, still, I hope I

shall be excused for adopting this plan, as I could not readily see how my views on this subject could be presented in any other way.

With sentiments of esteem,
I remain your obedient servant,
EBEN. A. LESTER.

To the Hon. S. D. INGHAM,
Secretary of the Treasury of the United States.

No. 18.

The committee have caused these extracts or translations from the circulars of the Director General of Roads and Bridges in France, under a belief that some practical information may be derived therefrom.]

Circular, No. 1, from the Director General of Roads, Bridges, and Mines, to the Prefets of the Departments.

PARIS, *April* 1, 1824.

MR. PREFET: You are acquainted with the royal ordinance of the 29th October, 1823, (No. 637 of the Bulletin of Laws, page 330,) and the conditions which, for safety, it imposes on high pressure steam engines, or those in which the elastic force of the steam employed is in equilibrium with more than two atmospheres, notwithstanding they should effectually consume their own smoke.

According to the 8th article, instructions in regard to the measures of precaution to be habitually observed in the use of those engines must be published and stuck up in the interior of the workshops.

The engineers of mines in the departments where they are stationed, and in default of them, the engineers of roads and bridges, being charged, according to article the 7th, to carry into effect the principal dispositions of this ordinance, I appointed a commission composed of engineers belonging to the two corps, the best versed in matters of this kind, and directed them to prepare a project of instructions on the measures of precaution for continual observance.

Those instructions have been approved, the 19th of March last, by his excellency the Minister of the Interior.

I have the honor to transmit you, herewith, copies thereof, which I pray you have published, and stuck up in the interior of those workshops wherein steam engines of the description defined in article the 1st of the ordinance of the 29th October, 1823, are employed.

You will likewise remit copies, in octavo, to the proprietors of engines, engaging them to prepare, if need be, an abridged abstract of the instruction for their own use, containing the special dispositions thereof, and, more particularly, those applicable or useful to the kind of machines they employ.

I am engaged in preparing the basis of other instructions on the means of carrying into effect the dispositions contained in articles 3d, 4th, and 5th of the ordinance, relating to the proof that the boilers should undergo, previously to their being worked, to the valves that must be adapted to each extremity of the upper part of every boiler, and to the two fusible metal disks destined to prevent the danger of explosion.

I shall likewise have the stamps manufactured which are to be handed over to the engineers, and are intended to be affixed to the boilers, for the purpose of indicating the degree of pressure for which the boiler has been constructed, and the degree of heat at which the metallic disks will fuse.

In the actual state of things, and in the interest of the manufacturers, I

pray you to watch, from the present, the enforcing the execution of the dispositions prescribed by article 6th of the ordinance, which states that "no boiler can be fixed in any locality of which the dimensions shall not be at least equal to twenty-seven times its cube."

"The place must be lighted from at least two of its sides by large windows, having light framed sashes opening outwards, and must not be contiguous to the party walls of neighboring houses, but must be separated therefrom, at a distance of two metres, by a wall of one metre in thickness, at least. It must also be separated from any interior work room, by a wall of the same thickness; and no work shop or dwelling room can be constructed above it."

I will do myself the honor, by another opportunity, to forward on to you, and likewise to the engineers of mines, and those of roads and bridges, new instructions relative to the valves, to the fusible metal disks, and to the application of the stamps.

I pray you, Mr. Prefet, to acknowledge the receipt of the present, and of the instructions it accompanies.

I have the honor to be, with the most distinguished consideration, Mr. Prefet, your very humble and very obedient servant, the Councillor of State, Director General of Roads, Bridges, and Mines.

BECQUEY.

Instructions on the measures of precaution constantly to be observed in the employment of High Pressure Steam Engines.

The employment of high pressure steam engines requires not only momentary precautions on the part of the firemen or engine workers to whom they may be confided, but also the vigilant inspection of the proprietors of those machines. In neglecting to observe those necessary precautions, workmen may cause the deplorable accidents of which they would infallibly become the first victims. In relaxing from that indispensable vigilance required on their part, the owners would become the indirect cause of those accidents, and expose themselves, otherwise, to considerable losses, such as may result from the destruction of the engines, the damage done to the buildings, and the entire cessation of their works.

It is the duty of every proprietor not to confide his engine but in the hands of a workman of acknowledged capability and intelligence; and who is, moreover, not only attentive, active, cleanly, and sober, but exempt from any failing calculated to prove injurious to the regularity of the service required. Nothing must disturb that regularity, or distract or call off the attention of the workmen from his task; otherwise, there can be nothing like security in the establishment.

The attention of the engine worker or fireman, and the vigilance of the proprietor, must be mainly directed to the following parts of the engine, viz. The fire-place, the boiler, and its generating tubes, the feed pump, and the height of water in the boiler, the safety-valves, and the steam or pressure gauge. Some precautions are also necessary to be observed in regard to the surrounding space.

Of the fire-place.

The principles by which the management of the fire must be directed are, to avoid, on the one hand, too sudden an increase of heat, and, on the other extreme, too rapid a degree of cooling. In both cases, the generating tubes

experience inequalities of temperature, more or less considerable, occasioning irregular degrees of expansion in them, and may thereby give rise to the production of cracks, and the appearance of leaks. The fire, therefore, at the commencement of getting up steam, must not be urged in too great a degree, particularly should the boiler and fire-place have been quite cold at starting; for, any time thus gained, would be at the expense of the security of the generating tubes.

As soon as the fire shall have arrived at the degree of intensity proper for the working of the engine, it must be conducted with regularity, and, to that effect, be supplied with the quantities of fuel previously determined on by experience, and raked up at proper intervals. Care must be taken to avoid letting the fire get too low; and should this take place, it is by no means proper to project, at any one time, too great a quantity of fuel into the fire-place; for the inevitable consequences of such precipitancy, which would, in the first place, have for effect the momentary cooling of the boiler, would be to occasion a development of heat both excessive and dangerous.

It will be proper, in respect to raking up the fire, and in adding fresh fuel thereto, to execute those operations in the least possible time; in the view of abridging the destructive action which cold air exercises on the generating tubes, when it is introduced with rapidity through the door of the fire-place.

Most of these precautions may be dispensed with when the furnace is supplied by a mechanical distributer or fire regulator, projecting the coal on the fire whenever it is necessary; but, in that case, the engine worker must be careful to ascertain that the regulator never wants for aliment, and that its operation is uniform and continuous.

The manner of extinguishing the fire, when not performed with care, is one of the most frequent causes of those accidents which sometimes occur to the generating tubes. The best method is to leave what remains of the fire on the grate, to shut close the damper in the chimney, as also the door of the ash pit, and to lute the latter, and also the fire door, with a little loamy earth. By proceeding in this mode, the air is hindered, not only from cooling the generating tubes too suddenly, but from oxydating their exterior surface, which would otherwise rapidly take place. This method has also for advantage the economy resulting from the saving of the residue of the fire; for this residue is soon extinguished from the want of air, and may then be removed without inconvenience.

Of the generating tubes, and of the boiler.

However pure the water employed may appear, still it always deposites an earthy sediment, which it is of importance not to suffer to accumulate, as this sediment would become harder and grow thicker in a short time, and thereby increase the difficulty with which the heat penetrates the tubes and boiler in quantity sufficient to produce steam of the proper degree of tension, and would consequently render a more intense fire requisite. The results thereof would be an increased expenditure of fuel, and augment the chances of deterioration and fracture.

Experience has shown that, by introducing a certain quantity of potatoes in the generating tubes and in the boiler, their substance combines with the earthy sediments under the form of a thin paste, and prevents the induration thereof; but in proportion as the sediment increases, this paste diminishes the production of steam, either in consequence of its vicidity, or by

the space it occupies. There is then a period when the removal of these deposites becomes indispensable; and this period occurs more or less frequently, according to the nature of the water; hence it becomes necessary that the owner of every engine should find out, by experience, the time that may elapse before it becomes proper to clean out the boiler; and also the *minimum* quantity of potatoes that should be employed. Those researches are not only interesting in point of security, but as affecting the relative economy with which steam can be produced.

When, in despite of every precaution, a crack should discover itself in one of the generating tubes, the engine worker should immediately apprize the proprietor of it, and the latter should lose no time in having the tube replaced: patching it up would merely have for effect the concealment of the mischief, whilst the danger of a rupture might be rapidly increasing.

The owner and engine worker should note, with attention, the progress of the superficial deterioration experienced by the generating tubes in the course of wear, principally those manufactured from sheet iron. They should not wait for the visit of the engineer to subject to a fresh proof such tubes as, from their thinness, inspire doubts respecting their solidity.

All which precedes equally applies to the boilers; but here, as the means for inspection are less multiplied, the engine worker and owner must profit of every opportunity that may be presented to ascertain the state of things, either when it becomes necessary to change one or more generating tubes; or whilst repairs are making to the fire-place, or to the setting of the boiler, or in fact at every time it becomes proper to empty the boiler for the purpose of cleansing it. In addition to which, any indication that the smallest leaks give, should by no means be neglected.

Whenever leakage takes place at the joint of the bonnet or lid which closes a generating tube, or at the one appertaining to the man hole of the boiler, no effort should be made to stop it, by screwing down the nuts of their bolts. Great danger would be incurred of fracturing those lids, particularly, should the cement forming the joints have had time to harden; for, in the event of such an accident happening, the workman would be killed by the fragments, or scalded by the water or steam. Those sort of leaks should never be repaired until after the work has ceased.

Whenever the generating tubes and boiler are about being cleansed, the proprietors must not require of their workmen to undertake to empty the water previously to the temperature having sufficiently subsided; particularly in respect to those boilers in which the bonnets of the generating tubes are unprovided with stop corks.

Of the feed pump, and of the proper height of water in the boiler.

It is of the greatest importance that the height of the water, which is indicated by the horizontal position of the lever moved by the float, should be constantly maintained. The engine worker must not satisfy himself of the height of the water by a simple inspection of the lever only, but must frequently assure himself that the movements of the float are perfectly unconstrained. To this effect, he must observe that the packing which surrounds the wire to which the float is suspended, does not confine it too much; for, should such be the case, the indications given by the float would cease to be exact.

These last precautions are equally necessary to be observed in those engines in which the movements of the float are directly applied to regulate the

feeding apparatus, conveying the proper remedy for the diminution of the water in the boiler.

To watch over the feed pump is equally indispensable. If, through any negligence, the height of water had considerably diminished in the boiler, immediately on its being perceived, it will be necessary to re-establish or increase, little by little, the supply thereof, otherwise accidents might result, as the water in rising rapidly against the sides of the boiler, heated perhaps to redness, would instantly produce so great a quantity of steam, that it is possible the increase of pressure resulting therefrom would prove superior to that which the boiler would be capable of withstanding. The danger of explosion would become imminent under similar circumstances, should the safety-valves not be in a state to act with freedom; or should they, in consequence of an imprudent or culpable practice, be surcharged with weights.

In general, the least inconvenience that a want of water is likely to produce in boilers, is to occasion fractures extremely prejudicial to them, even should there be no apprehension of explosion.

Of the safety-valves.

In those boilers where the safety-valves remain under the control of the engine worker, it becomes proper he should study their action, and ascertain well the degree of adherency they commonly contract with the seating upon which they rest; more particularly, after having been recently ground together. He should keep that adherency in mind, even should the valve be so constructed as to reduce the plain of contact with its seat to an extremely narrow circular zone. He must also assure himself, frequently, that the valves possess the freedom of action necessary for their proper performance; for which purpose, it will be necessary to lift up, from time to time, the extremity of the lever which sustains their loading, in order to ascertain that the valve has not contracted too strong an adhesion.

When the valves of a boiler do not possess freedom of action, and when, at the same time, they are subjected to their maximum load, they fulfill their object imperfectly; they confine the steam instead of permitting its egress; the steam accumulates and becomes compressed, and may, according to circumstances, acquire a degree of tension surpassing in force the resistance which the boiler is capable of opposing, and thereby cause it to explode.

This misfortune may also occur in consequence of having added weights to their ordinary maximum load in the view of increasing the energy of the engine. Those additional weights are extremely dangerous. Ignorance of the danger attending this act can alone excuse the proprietor directing it, and the workman in obeying his orders. The latter should be apprized that one of the principal effects resulting from an explosion, is to let off an immense quantity of scalding vapor, which would cause the most cruel death.

Dangers of this nature will be far less to be apprehended from those engines which are to be established in conformity to the royal ordinance of October 29, 1823; but in those, also, the valves will require to be frequently inspected, and kept in a state of perfect freedom; for, should their action become but slightly impeded, at the least increase of intensity in the fire, the steam, instead of being allowed to escape, would acquire additional heat and tension; and the term would soon arrive when the fusible metal disks, to be adapted to each boiler, would melt or be torn asunder; the work of the

establishment would be interrupted, and its proprietor be subjected to the inconvenience and loss of time incurred from having to replace the fusible disks. The owner is particularly interested in examining, daily, the valve enclosed in the iron grating, the key of which is to remain in his possession.

Safety-valves, in general, require frequent grinding, otherwise they are liable to allow a waste of steam. This precaution does not admit of neglect, for the workman could only remedy the omission, but by adding weights to their usual load. Now, owners can never proscribe this practice of adding weights with too much severity.

When the fire is no longer required, or when it is simply covered over with the intention of finding it next morning, the engine house must not be left, before ascertaining that the valves, properly unloaded, are capable of allowing the free escape of all the steam which may continue to be produced.

Of the pressure gauge.

The pressure gauge, in consequence of being in constant communication with the interior of the boiler, indicates, at each instant, the rapidity, more or less great, with which steam is produced; and the degree of expansive force or pressure resulting therefrom. This indication is given by the motion of the column of mercury confined in the glass tube, and is measured by the scale adapted to it.

This instrument is of great use, when it has been carefully constructed and correctly graduated. As it is fragile, the proprietor should take necessary measures to preserve it from accident, and, to this effect, have it protected by a grating of brass or iron wire.

The owner should also use his best endeavors to make his workman comprehend the destination and advantages of the instrument, to enable him to profit, opportunely, by the indications it affords.

And, lastly, the engine worker should, by all means, consult the pressure gauge very frequently, and take it always for his guide in the management of the fire, whatever may be the load; or, in other words, the pressure with which the engine is working, according to the power required in the factory.

Of the space surrounding the engine and boiler house.

In the supposition of an explosion taking place, the means of rendering its effects less likely to cause damage, is to keep the engine and boiler house completely isolated, and not to suffer any cumbersome or heavy articles on the premises to be kept nearer to it than at a distance of several metres. The owner would also place himself in contravention with article 6th of the royal ordinance of the 29th October, 1823, were he to encumber, with resisting materials, the space directed to be left free on the side next his neighbors, between the party walls and the wall of defence which must encircle the engine and boiler house. This wall of defence can only fulfil the object the royal ordinance had in view, but by being surrounded by a clear space.

To conclude, it is indispensable that the engine and boiler house should be capable of being effectually secured against intruders during the absence of the engine worker. It is easy to be conceived, for example, that, if through ill will or malevolence, the safety-valves should at any time be overloaded or fastened down by wedging, whilst the fire was stopped or covered up, the accumulation of steam might give rise to an accident. The measures of precaution suggested in this particular case, are of equal importance to those

already enumerated in what has heretofore been exposed. The foresight of the proprietors of these engines, and the vigilance of the engine workers, should never be in default at any time or under any circumstances.

PARIS, 19*th March*, 1824.

The Councillor of State, Director General of Roads, Bridges, and Mines:

BECQUEY.

Approved 19th March, 1824.

The Minister Secretary of State for the Department of the Interior:

CORBIERE.

No. 19.

CIRCULAR No. 2.

From the Director General of Roads, Bridges, and Mines, to the Prefets of the Departments.

PARIS, 19*th May*, 1825.

Mr. PREFET: I have already had the honor to address you, in conformity to the 8th article of the ordinance of the 29th October, 1823, (No. 637, of the Bulletin of the Laws, page 330,) certain instructions on the measures of precaution constantly to be observed in the employment of high pressure steam engines.

Questions of a scientific character, necessitating multiplied and exact experiments, and the aid of the Academy of Sciences, required solution before publishing the second series of instructions relative to the proof which boilers must undergo previously to their being employed, and to the two fusible metal disks which are to be affixed to the upper part of the same.

These instructions, which I address you herewith, have been prepared by the commission composed of Engineers of Mines and Engineers of Roads and Bridges, formed for the execution of the ordinance of 29th October, 1823. They were approved the 7th of this month by his excellency the Minister of the Interior. You will receive, with the present, — copies.

You will observe, at the conclusion,

1. A table of the elastic force of the steam of water at different temperatures, drawn up by the Royal Academy of Sciences.

2. The ordinance of the 29th October, 1823, relating to high pressure steam engines.

As the knowledge of those documents is indispensable to the manufacturers of boilers appertaining to high pressure steam engines, and interests likewise those who employ machines of that description, I must request you to address copies of the same to the one and the other, in order that they may not be ignorant of the obligations thereby imposed upon them.

The table already referred to is merely approximative, but the opinion of the Academy of Sciences, by whom it has been adopted, is, that the errors affecting the numbers are, at most, but two or three degrees of temperature, even in the highest parts of the scale: therefore, by means of the measures of safety prescribed by the ordinance, no inconvenience need be feared in practice.

The Academy is at this moment engaged in prosecuting further experiments, intended to give to this table all desirable precision. That body is

also occupied in researches which have for their object to determine the dimensions proper to be given to safety-valves. As soon as the results thereof are obtained, I shall lose no time in making you acquainted with them.

You already know, Mr. Prefet, that, should there be no Engineer of Mines stationed in a department, it becomes the duty of the Engineer of Roads and Bridges to act in his stead, in conformity to article the 7th of the ordinance, in order to superintend the proving of the boilers and of the metallic disks. The engineer deputed must examine the boilers once every year at least, note the state in which they are found, and order those to be replaced which, from the length of time they have been in use, or from any accidental deterioration, he may consider as having become dangerous.

You will inform the manufacturers of "high pressure steam engines, or those in which the elastic force of the steam employed is in equilibrium with more than two atmospheres, notwithstanding they should effectually consume their own smoke," that they are under the obligation of having the boilers, coming within the limits of the ordinance, verified, proved, and stamped, that they must address themselves to you, in order that you may designate to them the engineer charged with those operations, and that you may at the same time give the engineer the necessary orders.

As soon as you shall have informed me whether there exists any manufactories of engines and boilers in your department, I shall send you—

1. A die, or punch, destined to stamp the fusible disks, and a duplicate thereof, in case of accident to the first, or for the service of another district.

2. A punch, bearing a flower de luce, intended to mark the heads of the screws used to affix the stamps to the boilers: a duplicate will also be sent.

These punches are to remain in the hands of the engineers.

I send you, likewise, three fac similes *en cliché** of each kind of stamp; one of them must be deposited in the archives of the prefecture, and the other two placed in the hands of the engineers charged with inspecting the boilers.

Should the number of these articles not suffice for the service of the different districts of your department, I will from time to time add thereto, at your request.

You will not forget that, according to the 7th article of the ordinance, the authorities entrusted with the local police must continually keep an eye on all establishments using high pressure steam engines.

In cases of contravention, the owners of those establishments may incur the interdiction thereof, independently of any penalties imposed or damages awarded by a decision of the courts.

It is for you, Mr. Prefet, to prescribe all such measures as you may deem proper for the vigilant exercise of this superintendence. The preservation of life is materially concerned in the observance of the ordinance and instructions, which have moreover for object to prevent loss and discouragement to commerce and industry.

I have to request you will assure yourself of the execution of the measures prescribed by the present and by the accompanying instructions, and that you will send me an acknowledgment of their receipt.

I have the honor to be, &c.

The Councillor of State, Director General of Roads, Bridges, and Mines:

BECQUEY.

* For an explanation of the word *cliché*, see the end of this translation, p. 75.

INSTRUCTIONS, (SECOND SERIES,)

Relative to the execution of the Royal Ordinance of the 29th October, 1823, respecting high pressure Steam Engines, or those in which the elastic force of the steam employed is in equilibrium with more than two atmospheres, notwithstanding they should effectually consume their own smoke.

The royal ordinance of the 29th of October, 1823, has decreed that, henceforward, no high pressure steam engine boiler should be offered for sale (and for still greater reasons made use of,) that is not provided with two safety-valves, and with two disks of fusible metal, after having been proved by hydrostatic pressure, and stamped after such proof.

The manufacturer of high pressure engines and boilers, who should have boilers he wishes to have verified, proved, and stamped, must address his demand to the Prefet, who will immediately transmit the same to the Engineer of Mines, should there be one residing in the department, or, otherwise, to the Engineer of Roads and Bridges, who is to supply his place. (Article 7th of the ordinance.)

The Prefet must see that those operations are executed within the least possible delay, in order that no inconvenience may result thereby to commerce and to industry.

The engineer must ascertain, in the first place, if the dimensions of the two safety-valves are such that the action of one of them may suffice for the evacuation of the steam in the case of the vapour acquiring too much tension.

He must also verify whether the apertures in which the disks of fusible metal are to be fitted, are of a proper diameter; that is to say: for the first one, a diameter at least equal to that of one of the safety-valves; for the second, double that diameter.

He must also observe if those apertures are so situated as to enable the disks to fulfil their destination.

The proving of the boiler must only take place after the fusible metal disks are affixed to it. This fixation must be preceded by the following operations:

The engineer must determine, from the subjoined table, the degree of fusibility of the metal each disk is to be made of; he must subsequently verify whether the metal it is proposed to manufacture the disks out of is endowed with the degree of fusibility required. This verification may take place in two ways:

1. Should the metal have been prepared by the manufacturer of the boilers or engines, the engineer must proceed to the trial of the two kinds of ingots which are to furnish the matter of the disks, employing the apparatus the manufacturer himself makes use of, having previously ascertained its accuracy.

2. Should the manufacturer of the boilers or engines choose to employ fusible metal bought in commerce, the engineer will only have to observe whether the two ingots bear the legal stamp, stating the degree at which they are fusible; that is to say, whether they are both marked with the stamp which ought to be affixed to them by the Engineer of Mines deputed to make this kind of assays at the manufactory of fusible metal: this stamp should be similar to the one which will be described in the underwritten paragraph.

The engineer having previously acquired the assurance that the ingots

are composed, the one of a metal melting at ten centigrade degrees above the temperature it is proposed the steam should habitually possess in the boiler, and the other of a metal melting at twenty centigrade degrees above the said temperature, must proceed to have two disks cast in his presence, and affix to each an octangular stamp, bearing for legend the words "*roads, bridges, and mines,*" in the centre of which stamp he shall cause immediately to be engraved, under his own inspection, the degree of fusibility of the disks.

The disks must then be affixed to the boiler.

In case the engine manufacturer should have procured disks ready cast, and which have already been assayed and stamped at the place of their manufacture, the engineer will only have to verify the stamp indicating the temperatures, previously to the disks being affixed to the boiler.*

In general, in verifying the degree of fusion of fusible metal, the engineer must keep in mind that the question is, not to determine the degree at which the metal becomes perfectly fluid, but the point at which it softens sufficiently to give way under the pressure of the steam. This distinction is of importance, for the disks of fusible metal are susceptible of losing their tenacity a little before reaching the temperature that determines their perfect fusion. The stamp must consequently express, not the degree of perfect fusion, but that which softens the metal sufficiently to render the disk susceptible of giving way under the pressure it will experience at that temperature.

The boiler being previously provided with its generating tubes, its fusible disks, and its safety-valves, properly loaded with weights, must then be filled with water, and proved, by subjecting it to the action of a hydrostatic press, or force pump, which must be furnished by the manufacturer, together with the labor necessary for its employment.

The pressure exerted must be five times greater than the one the boiler is destined to be subjected to in the regular working of the engine of which it forms a part; that is to say, should the boiler, for example, be destined to work at two atmospheres, the proof pressure must be carried to ten atmospheres.

As soon as the boiler shall have resisted this proof, the engineer shall cause to be affixed, in his presence, the stamp which is to indicate the pressure at which the engine will habitually work, expressed in atmospheres.

This stamp will consist in: 1. A circular plate of copper, struck at the Mint of Paris, bearing for legend the words "*Ordinance of 29th of October,* 1823," and on which the number of atmospheres and semi-atmospheres is to be stated; 2. In three screws of the same metal, whose object is to affix the plate to the body of the boiler, by means of screwed holes tapped in the same. As soon as the screws shall have been screwed tight, the engineer shall direct their heads to be filed down level or flush with the plate, in such a manner as to cause the entire disappearance of the slits previously existing on them; after which, he must stamp the head of each screw with an engraved punch bearing a flower de luce, having a diameter greater than that of the said heads.

The plate and screws of copper must be furnished by the manufacturer.†

* Manufacturers may obtain fusible metal for every degree of temperature required, prepared after the indications of Mr. Gay Lussac, member of the Academy of Sciences, from Mr. Collardeau, rue de la Cerisaie, Paris.

† Manufacturers may provide themselves with every description of these articles, and for the price of the labor only, at the Royal Mint for Medals, rue Guénégaud, No. 8, Paris.

By means of the preceding dispositions, all boilers of high pressure steam engines will be proved at the place where they are manufactured, which will have the effect of concentrating the provings within a small number of departments.

Should there be no boiler factory in a department, the duty of the engineer in regard to the boilers which may be introduced into it, either for the use of high pressure engines already authorized, or for new engines requiring authorization, will consist in verifying the two species of stamps with which the boilers must be provided. Those verifications will be easily made by means of the *clichés*.

A copy of those *clichés* is deposited in the archives of the prefecture, another at the office of the Engineer of Mines, should there be one, otherwise at the office of the Engineer of Roads and Bridges.

PARIS, 7*th May*, 1825.

The Councillor of State, Director General of Roads, Bridges, and Mines:

BECQUEY.

Approved, 7th May, 1825.

The Minister Secretary of State for the Department of the Interior:

CORBIÉRE.

TABLE of the Elastic Force of the Steam of Water at different temperatures.*

Elasticity of the steam, taking the pressure of the atmosphere for unity.	Height of the column of mercury which measures the elastic force of the steam.	Temperature which corresponds on the centigrade thermometer.	Pressure exerted by the steam on each square centimetre of the valve.
Atmospheres.	*Métres.*	*Degrees.*	*Kilogrammes.*
1	0.76	100	1 033
1½	1.14	112.2	1.549
2	1.52	122	2.066
2½	1.90	129	2.582
3	2.28	135	3.099
3½	2.66	140.7	3.615
4	3.04	145.2	4.132
4¼	3.42	150	4.648
5	3.80	154	5.165
5½	4.18	158	5.681
6	4 56	161.5	6.198
6½	4.94	164.7	6.714
7	5.32	168	7.231
7½	5.70	170.7	7 747
8	6 08	173	8.264

* This table was drawn up by the Royal Academy of Sciences.

Ordinance of the King, containing Regulations for High Pressure Steam Engines.

PALACE OF THE TUILLERIES, *29th October*, 1823.

Louis, by the grace of God, King of France and of Navarre, to all to whom these presents shall come, greeting:

Upon the report of our Minister, Secretary of State for the Department of the Interior, and our Council of State being heard, we have ordered and do order as follows:

Article 1st. High pressure steam engines, or those in which the elastic force of the steam employed is in equilibrium with more than two atmospheres, notwithstanding they should effectually consume their own smoke, can no longer be established but in virtue of an authorization obtained in conformity to the decree of the 15th October, 1810, in relation to establishments of the second class.

They must, over and above, be subjected to the following conditions imposed for security.

Article 2d. At the time the authorization is demanded, the owners of the establishment shall be required to declare at what degree of pressure their engines are to be constantly worked.

They can in no case exceed the degree of pressure stated in their declaration.

The pressure must be estimated in units of an atmosphere, or in kilogrammes per square centimetre of the surface exposed to the pressure of the steam.

Article 3d. The boilers of steam engines, working at high pressure, shall not be offered for sale, nor employed in any establishment, previously to their strength having been ascertained by hydrostatic pressure.

Every boiler must undergo, in proving, a pressure equal to five times that to which it will afterwards be subjected in the regular working of the engine it is intended to supply.

After proving, and as evidence of the result thereof, every boiler must be marked with a stamp indicating, in figures, the degree of pressure for which it has been constructed.

No owner of any establishment shall employ a boiler that does not bear a stamp expressing, in figures, a force equal to the degree of pressure stated in their declaration.

Article 4th. To each boiler must be adapted two safety-valves, one at each extremity of the upper part; their dimensions and their loads must be equal, and must be regulated not only by the size of the boiler, but by the degree of pressure shown by the stamp, and always in such a manner that the action of a single valve may suffice for the evacuation of the steam, in case the tension should accumulate to too great a degree.

One of the valves may remain under control of the workman having in charge the fire or the engine; the other must be placed without his reach, and covered by a grating of which the key is to remain in the possession of the owner of the establishment.

Article 5th. There must also be adapted to the upper part of every boiler two metal disks, fusible at temperatures to be presently determined.

The first, in diameter at least equal to one of the valves, must be composed of such a metallic alloy as will melt, or soften sufficiently to be torn asun-

der by a temperature of ten centigrade degrees above the degree of heat indicated on the stamp attached to the boiler.

The second, double in its diameter to the preceding, must be placed near the safety-valve, and shut up under the same grating The metallic alloy composing it must be of a nature to melt or soften sufficiently to be torn asunder by a temperature of twenty centigrade degrees above the degree of heat indicated on the stamp borne by the boiler.

Those disks must be marked with a stamp showing, in figures, the degree of heat at which they are fusible.

Article 6th. No boiler can be fixed in any locality of which the dimensions shall not be at least equal to twenty seven times its cube.

The place must be lighted, from at least two of its sides, by large windows having light framed sashes opening outwards, and must not be contiguous to the party walls of neighboring houses, but must be separated therefrom at a distance of two metres, by a wall of one metre in thickness, at least; it must also be separated from any interior work room by a wall of the same thickness; and no workshop or dwelling room can be constructed above it.

Article 7th. The Engineers of Mines in the departments where they are stationed, and in default of them, the Engineers of Roads and Bridges, are hereby charged with the superintendence of the proving of the boilers and metallic disks, and will cause them to be marked with the stamps with which they will be furnished for that purpose.

The said engineers are, in their inspections, which must take place once a year at least, to assure themselves that the conditions hereby imposed are rigorously fulfilled; they must examine the boilers, note the state in which they are found, and order those to be replaced which, from the length of time they have been in use, or from any accidental deterioration, they may consider as having become dangerous.

The authorities entrusted with the local police must continually keep an eye on all establishments using high pressure engines.

In cases of contravention of the dispositions of the present ordinance, the proprietors in fault shall be liable to incur the interdiction of their establishment, independently of any penalties imposed or damages awarded by a decision of the courts.

Article 8th. Our Minister, Secretary of State for the Department of the Interior, will publish instructions on the measures of precaution constantly to be observed in the employment of high pressure steam engines.

Those instructions must be stuck up in the interior of the workshops.

Article 9th. Our Minister, Secretary of State for the Department of the Interior, is charged with the execution of the present ordinance, which must be inserted in the Bulletin of the Laws.

NOTE TO PAGE 70.

I have been induced to retain the French term *en cliché*, from the want of a technical word, of equivalent signification, in the English language. I might indeed have omitted it, and contented myself by using in its stead either of the words "fac simile," "model," or "pattern," simply, but as there may readily exist different kinds of fac similes, models, &c., and as the term *cliche* defines the precise sort which was sent in the present instance,

I concluded to retain the word, and explain its signification in a note, in preference to attempt doing it by means of a long pariphrase in the body of the document. The word cliché, then, is applied to any impression made by a die or stamp, on the fusible metal formed by alloying tin with lead and bismuth, or on alloys of tin or lead with the regulus of antimony, at the moment when they are passing from the fluid to the solid state. Thus fac similes of gold, silver, or copper medals, are made, *en cliché*, by first impressing the medal on a mass of one of the abovementioned alloys, for the purpose of obtaining a die or *creux*, which, in its turn, is used to obtain copies of the medals *in relievo*, by impressing it on any one of the said metallic compounds—a process which bears a considerable resemblance to the French mode of stereotyping. This art was totally unknown in England but a very few years since, and I suppose has not as yet been introduced in the United States, though its application to various useful purposes is sufficiently obvious.—(*Translator.*)

No. 20.

Report of a Joint Committee of the Legislature of the State of Louisiana, on the petition of J. O. Blair, upon the subject of Steam Explosion.

The Joint Committee, to whom was referred the petition of J. O. Blair on the subject of steam explosions, beg leave to submit the following report:

That they have carefully examined the drawings exhibited to them by the petitioner, and feel bound to say that the powers of mind displayed in the mechanical arrangement of matter to counteract the cause of steam explosions, are worthy of an ingenious mind, and merit the attention of Government.

Your committee are of opinion that all the important causes of steam explosions, together with their remedy, have been explained by the petitioner; and that all that is wanting to render the steam engine secure from explosion, is possible, and can be effected by a re-organization on the principles designed by petitioner, who has shown that a steam-generating apparatus can be so contrived as to prevent the fire from coming in contact with any part of the boiler unprotected by water; and, if so, it appears to your committee that the danger of explosions will be much lessened thereby, if not entirely removed.

Your committee have been presented with drawings projected for the purpose of explaining the principles on which the steam generating parts of the machine can be changed so as to keep the boilers full of water.

Your committee further report, that the petitioner has demonstrated the strength of boilers by a diagram formed for the purpose, and that, in demonstrating their strength, has shown that there cannot be a steam explosion where the boilers are made of good common materials, and on the best known form, and well supplied with water, so as to protect every part of them exposed to the action of the fire.

In another drawing, he has shown that if the water only cover the flues of the boilers when the boat is running level, and if the boat heel to one side but six inches, and the boilers are twenty feet in length, many feet of the boilers are exposed to the action of the fire, unprotected by water on one side, and an extreme pressure of steam on the other. If the boat remain

in this position until the exposed part, unprotected by water, becomes heated to a certain degree, an explosion must be the inevitable consequence.

In another drawing is shown a hydrostat for governing the water in the boilers. This machine is a species of engine. The water from the forcing pump is forced to act on the piston when the water in the boilers is as high as desired for safety.

The action of the water on the piston enables it to escape into the air until the water in the boilers has sunk an inch or less.

At that instant, the water takes another direction, and is all forced into the boilers until it is as high as desired, when it again acts on the piston, and escapes into the air before it arrives at the boilers, and so on, alternately; thereby making the steam-generating parts of the engine a self-regulator of its water, without the attention of the engineer being constantly required.

The long catalogue of steamboat disasters which have taken place from the cause under consideration, are too well known to require an enumeration. They call loudly for a remedy.

It appears to your committee, that, when a plan is offered which affords so strong a probability of being an effectual remedy for the evil, that it is the duty of Government, in protection of the lives and property of its citizens, to lend the aid necessary to test fully the proposed invention, and it becomes most properly the duty of the General Government, which alone has the power of securing by patent the rights of the inventor.

It is in evidence before your committee, that an engine, on the principles described by the petitioner, is now in successful operation on the plantation of Judge Butler, from whom your committee have obtained valuable information. This gentleman informs us that the engine appears to answer every useful purpose; that he made his last year's crop with it, with a great saving of fuel, and without the slightest accident; that he considers it an important improvement, and deserves to be encouraged.

With these views, your committee beg leave to submit the following resolution.

J. THOMAS,
THO. C. NICHOLS.

Resolved by the Senate and House of Representatives of the State of Louisiana in General Assembly convened, That our Senators in Congress be instructed, and our Representatives requested, to use the proper exertions with the General Government of the United States to have a full and fair experiment of the utilty of J. O. Blair's method of generating steam, and preventing the explosion of steam boilers.

A. MOUTON,
Speaker of the House of Representatives.

C. DERBIGNY,
President of the Senate.

Approved, March 31, 1832.

A. B. ROMAN,
Governor of the State of Louisiana.

A true copy from the original.

THO. F. McCALEB,
Secretary of State.

To the honorable the Senate and House of Representatives in Congress assembled:

The petition of Joshua O. Blair, of the city of New Orleans, State of Louisiana, respectfully showeth:

That your petitioner has, for several years last past, been diligently engaged in investigating the causes of steam explosions, from a full conviction, on his part, that, were the causes fully and clearly explained, a remedy could be applied.

Because, from several demonstrations of the strength of boilers, it appears that the largest (the largest being the weakest) boilers now in use will sustain more than six and three-fourth times the pressure used or wanted in high or low pressured engines.

From this, it is evident that some cause, or combination of causes, are united in construcing the steam engine which render it very imperfect. The principal cause of steam explosions may be attributed to the impossibility, on the part of the engineer, to keep the water at its proper height; sometimes to the heeling of the boat, which exposes parts of the boilers to the fire, unprotected by water.

The following are some of the facts adduced by practical engineers, showing the difficulty to keep the water at the proper height.

In long voyages, frequently, from carelessness, inattention, and perhaps, oftener from fatigue, the engineer finds he has neglected the governing valve of the water leading to the forcing pump, and that the boilers are too full of water, thereby weakening the power of the engine by the emission of water into the cylinder of the engine.

To remedy this, the water leading to the forcing pump is stopped; again it is neglected till the water is found too low: the engineer then lets on the water; but, from leaks in the valve between the forcing-pump and the boilers, the barrel of the pump becomes filled with steam of such destiny that it totally prevents the admission of water into the pump.

The engineer, supposing the pump to raise the usual quantity of water, suffers the boilers to remain without examination some ten or twenty minutes, the usual time; he then tries the gauge cocks, and finds the water too low; he then puts on, as he supposes, all the water, and attends to the working of the engine some ten or twenty minutes longer, at which time he tries the height of the water, and finds it still too low. He then, if intelligent, sets himself to work, and attempts to cool the barrel of the pump by pouring water on the outside, which takes considerable length of time: this, added to the time employed in trying to work the water into the pump, would make some forty to sixty minutes.

During this time, if the fire be kept up, and such is always the case, the water is continually becoming lower, and parts of the boilers, not covered with water, directly exposed to the fire, the exact extent of surface varying in exact proportion to the time taken, and the quantity of heat to which it is exposed.

If the time in regulating be so long that the water in the boilers is reduced two inches lower than the top of the flues, about three hundred feet of boiler surface is exposed to the direct action of the fire in boilers 3 feet in diameter and 20 feet long, with 2 flues 14 inches in diameter in each boiler, as per plate No. 4, herewith shown.

Again, the parts exposed to the fire become weakened in exact propor-

tion to the intensity of heat: if iron be heated to red heat, it has not more than one-sixth the strength it has in common atmospheric heat, and if it be six or nearly seven times the strength required, as stated above, when heated to a red heat, it is near the breaking point. (See Renwick, p. 77.)

Suppose, for further explanation, a boiler as described, working 100 lbs. to the inch, is heated to a red heat, which boiler, before it is heated, is capable of sustaining a pressure of 678 lbs., the boiler, in its heated state, being only one-sixth the original strength, only requires 13 lbs. additional pressure to burst.

But, should the iron be heated several degrees above red heat, it would be so weakened that the 100 lbs. pressure would be sufficient to burst the boiler without any addition.

In fact, in the furnaces as constructed, iron (if the heat were continued any considerable length of time,) without water to protect it, would melt and fall to pieces without any other pressure than the atmosphere and earth's attraction.

If the boat should heel, strike a shoal or log suddenly, and throw the heated water on the heated iron while laboring under the practical difficulties, covering three hundred feet of red hot iron with hot water, six gallons of which, if spread over half the surface equally, would not cover it the thickness of a sheet of common writing paper, or, $\frac{78}{1000}$ of an inch; this, in a density of six atmospheres, would be transformed into nearly 1,700 gallons of steam in from two to eight seconds, (according to Klayporth's experiments,) the pressure of which, upon the boilers already weakened by the intensity of heat, must cause them to burst immediately.

Facts might be enumerated to prove that steam exposed to, and resting upon heated iron, under a pressure of some 3 to 6 atmospheres, say 45 to 90 lbs. to the inch, loses its elasticity as it becomes heated in some ratio not as yet demonstrated; it would become greatly heated under this pressure, if exposed to red hot iron, perhaps to the temperature of red in the dark, as is proved in the following instance:

The steam in Doctor Buchanan's capillary engine, erected some eight years since at Louisville, Kentucky, burned hemp bands in the open air several feet from the generator: these bands were wrapped around the pipe which conducted the steam to the engine at different distances for experiments, after an unusual quantity of heat was discovered to be held in the steam; and, as the heat increased, the bands would take fire, one after another, as the heat advanced along the pipe.

During this time, the engine was observed to work with less power as the heat in the steam increased.

It is highly probable that the only reason that heated boilers do not always burst is this fact—that the steam loses its elastic force when it is over heated, thereby lessening the pressure as the iron is weakened with heat.

But if the safety-valve be hoisted, which is often done, when the boat is stopped to put out, or take in passengers, freight, &c.; and if, at the same time, the iron be heated intensely, and the steam also intensely heated, the water which was before laying quietly, being pressed with the steam, is relieved, and it will rise with violent ebullition, or, as the pressure is take off, the steam in the water rushes up through the water into the heated steam, carrying with it, in each particle heated water, which would be converted into steam by the intensity of its heat, and this would also revive the elasticity in the steam which was before over heated. [See Renwick, pages 95, 96;

97.] About three hundred feet surface of water would have the particles of steam, instantly, throwing all the water, of which they were capable of carrying, into the intensely heated steam: it would produce a pressure which would require an inconceivable strength to confine. The safety-valve cannot reasonably be considered as security when the steam is accumulating with such astonishing rapidity. Practical engineers know that the water not only raises into the steam, but that it often raises into the air when the safety-valve is hoisted.

Cagniard de la Tour discovered that water, at about the melting points of zinck, 680 degrees, expands at once into steam at about four times its original bulk.

These demonstrations prove the following position: If water be exposed to a temperature of 680 degrees, it all assumes a state of vapour, and, if subjected to double that heat, or 1,360 degrees, (red in the dark being 1,075) after it had imparted one half or 680 degrees, it would still remain at the temperature of melting *zinck*.

The largest locomotive engines having eight forty-two inch boilers, with double flues in each boiler of twenty feet in length, and eighteen inches in diameter, would expose a surface of 590 superficial feet to the direct action of the fire, if the water were four inches below the top of the flues: this surface, at the temperature of 1,360 degrees, is capable of converting into vapour a sheet of cold water in *magnitude equal to itself*, being 83 gallons, and then retain the temperature wanted to hold *zinck* in a state of fusion; but, suppose the water to be at the temperature of 320 degrees when exposed to the heated iron, the quantity would be increased to 107 gallons.

This would be converted into steam in the space of about from 6 to 20 seconds, as per the experiments of Klayporth. Water converted into steam enlarges in bulk 1,696 times: this would raise the whole extent of surface (590 feet,) fifty-three feet under the pressure of one atmosphere; and, under twenty atmospheres, two feet and a half, it would be folly gravely to declare the boilers must burst, the proof being demonstrated.

To sustain the pressure, the boilers must support a power equal to 35 or 40 atmostpheres, at least 525 lbs. to the inch.

Were it possible to confine the steam in any manner to the height which would be produced under such circumstances, the momentum in freeing it from its confined state would be 525 lbs. to the inch, only 6 lbs. less than the momentum of a 12 lb. ball urged with the velocity of 600 feet per second.

But boilers, at a red heat, break at 113 lbs. pressure; therefore the effect is never produced.

In the researches made on this subject, great pains have been taken to collect all the facts with respect to the different phenonema of bursting of boilers; and, also, that of the explosion of boilers, which have been treated as one and the same class.

Of the first class, the four following instances are named:

1st. Some boilers collapse, or are pushed together by the pressure of steam, as in the case of the steamboat *Ramisso*, and several others that might be named.

2d. The heads of boilers have burst off, and no other breaking has taken place, as in the case of the Car of Commerce.

3d. Is a case of bursting immediately after the safety-valve was hoisted at Essone, noted by Renwick, page 315.

4th. The Chief Justice Marshall, on the Hudson, burst at the instant of setting the engine in motion, and, at the same time, the safety-valve was open, and the steam escaping freely.

These are cases of bursting under different circumstances, the causes of which, we think, is explained.

Of the second class which are properly called explosions—the following are four cases of this class:

1st. The Hellen McGregor exploded at Memphis in 1830, threw off her aft head, and, at the same time, her boiler started forward, exerting a force which broke heavy timbers in the bow of the boat, carrying all before it. It plunged into the river.

2d. A boiler of wrought iron, weighing 9 tons, was erected in Lockrin, an immense distillery in Edinburg, exploded, having two safety-valves, and, for greater security, one of them was contained in a cage, and locked up, to prevent the workmen from overloading it. The instant of the catastrophe, the boiler divided into two distinct and unequal parts.

The upper part weighed 7 tons.

It was projected upwards with such force that, after having traversed the brick vault that covered the workshop and roof, it arose in the air to the height of 70 feet; the bottom, weighing 2 tons, was carried into the air 14 or 15 feet. See Renwick, page 310.

Also, from Judge Walker, of Lafourche, State of Louisiana, I learn that, at Pittsburg, some 12 or 15 years since, an explosion took place in a manufactory; one of the boilers was precipitated into the air, as it was supposed, 150 feet, and landed about three hundred yards from the manufactory, a case corresponding with the one last mentioned: they are considered as belonging to the same class.

3d. The Grampus, a towboat, plying between New Orleans snd the Balize exploded, and all the boilers burst simultaneously; the flues were all torn to pieces, and scattered in every direction, and the plates around the boilers were torn to pieces and flattened, indeed, every bolt was loosened; and the catastrophe spread destruction on all quarters; the boiler deck was precipitated in the air 15 or 20 feet, carrying Captain Morrison, master of the boat, without charge for passage. The iron appeared to be destroyed, being brittle like iron burnt out. Renwick, page 311, notes a similar occurrence of the steamboat Rhone, also a towboat between Arles and Lyons, having four boilers: three out of the four exploded simultaneously. The whole deck was blown a vast distance; the flues and chimney, weighing more than thirty hundred, rose vertically a considerable height. The vault of one of the boilers fell at a distance of more than 800 feet, although it weighed at least a ton.

4th. Two boilers exploded at the tin mine of Polgooth almost simultaneously. It was found that the cylinders or flues of both boilers were twisted upon themselves, and torn in a great number of places.

A similar case at the mine of East Erennis—the inner cylinder or flue was not only flattened by the approach of its upper and lower surfaces, but had even been thrown out of the building with great force.

In both the above cases, the outer cylinder sustained no injury.

These are supposed to be instances which embrace the different causes of steam explosion, as they are termed here; and the same, when explained, will appear to be sufficient to embrace all the phenomena that may present a subject of inquiry.

But for an explanation of the first class, denominated bursting:

1st. Boilers callapse, as it is called, when the flues become weakened at the top: by being uncovered with water and exposed to the heat of the fire, the pressure of the steam is too powerful for their strength to resist.

2d. When the heads burst off, the phenomena is explained thus, in a satisfactory manner.

The heads, which are plain, are cast iron, some inch and a half thick: they become heated, and being so thick, the water is not a complete protection even when they are covered. But, when uncovered, their situation being near the turning of the flues where the fire has a double action, they become excessively heated, and, being so heated, if the boat heel, or if the safety-valve be opened, the heads would convert into steam more water than any other part of the boiler, and the place where the steam is generated the pressure is the greatest; also, the steam nearest the heads, when thus heated, would be more intensely heated, and, if the valve were hoisted, the pressure in either case would be exactly the same, and the phenomena spoken of the result.

The third case has been so fully explained in the preceding subject, where the consequences of hoisting the safety-valve when the steam was excessively heated is stated, that it is unnecessary to explain further.

The same may be said of the bursting of the Chief Justice Marshall: the water must have been too low, and the working of steam and raising the safty-valve produced the effect, as explained, by the water being carried into the heated steam, or, possibly, the heeling of the boat threw the heated water on the hot iron. The effect would be the same in either case.

In fact the causes of bursting of this kind have been understood, for some years, and are largely entered into, and would seem clearly elucidated.

But how account for the cases enumerated in the second class—the cases termed explosions—how investigate or throw the least light on the subject?

The engines could never sustain the pressure, nor could the steam be formed so suddenly as to produce such tremendous results. Nothing can be more terrible, not even the artillery of heaven.

Any reflecting man, who is the least acquainted with the formation of steam, must be convinced that it is impossible for steam to be the cause of boilers exploding from any pressure it could produce.

It would be necessary to create, in a twinkling, an unknown quantity, and that which would exert a million times the force that was exerted the instant before.

This conceded, we must trace these most alarming explosions to other causes.

And here is the acme of human investigation on steamboat inquiry.

Here is the starting point of science.

"It is looking into the book of nature, unsealing her mysteries, and setting her captives free."

What a spectacle!—a steamboat brought to such perfection that it is no longer looked upon as a god, striking the contemplator with terror!

A steamboat may be so looked upon.

From the facts which have been gathered on this subject, and from the reasons psoduced in the investigation of cause and effect, the different phenomena of these tremendous explosions are accounted for satisfactorily, although they have been supposed to be enveloped in the mysteries of that chemical labyrinth over whose secrets nature presides.

The following conclusions are suggested by diligent research, and they are advanced with the fullest conviction that experiments cannot contradict them.

Sulphate of lime is held in solution in water. When water is heated to a temperature of 200 degrees, or more, the sulphate of lime is disconnected with the water, and becomes a distinct substance, this attaches to the iron; but, it being governed by the laws of gravity, the incrustation will attach to the bottom of the boiler and the top of the flues in largest quantities: this incrustation, so attached to iron, becomes a dense substance—sometimes ¼ to ½ inch in thickness.

When the water sinks below the top of the flues, which are exposed to the direct action of the fire, as soon as the fire becomes heated and expands sufficiently to break the incrustation of the sulphate of lime, the steam is exposed to the heated iron, and decomposes.

The oxygen unites with the iron, and the hydrogen, being freed from the oxygen, and six times lighter than steam, raises to the top of the boiler.

As the water falls in the boilers, and the top of the flues become more heated, the oxygen, which was freed from its chemical union with hydrogen, is freed from the heated iron surcharged with caloric which would cause it to rise to the top of the steam, and, from the affinity it has for hydrogen, it again mingles with the hydrogen, forming a mechanical union, and acts as a supporter of combustion at the temperature of 800 degrees: as the oxydized scales raises from the iron, it is prepared to decompose steam as in the first instance, and, probably, chemical union and decomposition constantly is taking place.

It will be remembered, at the same time, that, on parts of the flues near the water, hydrogen is freed from its accompanying component of steam oxygen, and that the hydrogen is raising to the top of the boilers.

Also, the sulphate of lime, being broken up, and thus exposed to intense heat, would decompose; the acid rising in a gaseous state, whose oxygen unites with the hydrogen, and acts as a supporter of combustion.

Thus is formed a magazine charged with combustion, which, if heated at any point to the temperature of 800 degrees, explodes with a flash exerting a force more powerful than gunpowder.

This being the case, suppose the boat to heel, the hydrogen being about six times lighter than steam, the combustion would take the higher parts of the boilers, and thus be exposed to heat, which would ignite being brought upon the heated iron. *See plate, No.* 4.

But if the boilers be stationary, all that is wanted is time to fill the upper parts of the boilers so full of combustion (and the more combustion the greater the explosion,) that the heat may approach it at the temperature of 800 degrees.

As the hydrogen formed and supplied with oxyen, (the supporter of combustion,) rises to the top of the boilers, and as the upper part of the boilers are fitted with the above properties of combustion, the steam, being kept lower, is more exposed to the heated iron. As the steam becomes heated, and its elastic force becomes weakened, it is capable of occupying less space: the chemical union is supposed to be weakened in exact ratio to the intensity of the heat to which it is exposed; and, from a chemical union of the steam, the union may become mechanical, and the greater part of the steam be hydrogen mechanically united with oxygen.

This, together with the oxygen surcharged with caloric escaping from

the heated iron, perhaps first chemically united with the lime produced from the sulphate of lime, or formed from the sulphate of lime, would form a conductor of fire to the charge of combustion like the electric touch; and then all the phenomena of engine explosions are explained, when it is recollected that the combustion has unbounded strength, sufficient to sweep away any thing with which it has been known to come in contact, as may be seen by the experiments of Parks.

It may be objected, and it would appear to a superficial observer, that, as the steam used in working the engine is taken from the top of the boiler, the hydrogen collected at the top would pass through, and not the steam.

This, although it has required deep investigation, has been demonstrated, as will be found in Ferguson on the Laws of Motion, to be exactly the revery of the above position.

The demonstration proves that matter of several different densities, acted upon by any given momentum, the motion produced on these bodies will vary in exact proportion to the difference of their several densities.

This being the law that governs matter in motion, it follows that, as steam is about six times heavier than hydrogen, the instant the engine was set to work, the steam would rush six times faster than the hydrogen, and almost instantly fill the pipe leading to the engine, and the current of steam would pass through in its proper channel, and, being more dense than the hydrogen, it would completely stop the hydrogen from passing, in the same manner that safety-valves prevent the steam from passing off.

The second class of steam engine catastrophes, called explosions, and classed under one and the same head, must have taken place from the igniting of the gases and blowing up the magazine formed in the boilers, in the manner we have been examining.

This petition is already lengthened to a much greater extent than was anticipated.

It is believed the matter and form would not be more acceptable to enter into the particulars of each case cited in explosions; the enumerations will be dispensed with, and these passing remarks introduced.

Although there is a striking difference in the cases denominated explosions, yet they are to be attributed to the same cause: all depend upon the quantity of gas collected, operating as a charge.

If the quantity be large, and such has sometimes been the case, nothing more devastating can be imagined.

If less, then, as would seem has been sometimes the case, the effect would not be so extraordinary.

And where several boilers have been torn to pieces simultaneously, it is believed the fire may have, at one explosion, forced itself into the other boilers by its expansive flash, or the pressure produced may have forced the steam, heated to 800 degrees, into the properties of combustion.

Again: the point or end of the boilers where the fire is first communicated to the combustion, may have considerable influence; as the boilers when not blown to pieces, are generally thrown forward, and it is believed that the fire is first communicated aft, as the heat there is most usually greatest on the flues.

No explosion, or bursting, as yet, has ever come to my knowledge where the boilers were well covered with water, and where the boat did not heel, unless in cases where it was found that the boiler was made in a bad manner, or of bad materials, or the valve was overloaded.

There are other chemical causes which contribute to the formation of combustion, which are believed equally important in the investigation, which are omitted; first, from the fact that, in the collection of this matter, they were mislaid, and more in consequence of the great length to which this petition is extended: they are, however, produced from the same cause. If any further information is wanted, it will be forwarded, without delay, on application.

Your petitioner would, with due deference to the understanding and intelligence of your honorable body, submit to your consideration the plan suggested to him by a long series of study and critical investigation, which is represented on the plates and drawings herewith shown.

Plate number 1.

This is a hydrostat placed upon a common boiler now in use.

This would render safe all stationary engines, and it would render boats safe with common boilers if they were never to heel.

Plate number 2.

This is a longitudinal cut through the hydrostat and improved boiler, showing all the openings, and the two nosels.

These improved boilers are so constructed that, if the boat should heel, no part of them would be exposed to the fire unprotected by water, if the proper quantum of water were let in.

The hydrostat should always be placed on the centre boiler, that, if the boat were to heel much, or none at all, the same quantity of water would be kept in the boilers; the centre being the point of oscillation, the buoy in the hydrostat would operate the same under all circumstances.

Plate number 3.

This is a transverse section of seven boilers on the improved plan: the plan on which it is projected is drawn through the nosels nearest the hydrostat, as seen in plate number two.

Plate number 4.

This plate has been referred to in the investigation and observations made on the heeling of boats: it shows six common boilers with two fires, each fourteen inches in diameter, heeled six inches.

It shows the level of the water, and the parts of the iron boilers and flues exposed to the fire, unprotected by water.

These plates have explanations on them easily understood, to which you will refer.

On the improved plan, the flues are entirely dispensed with, as they are not needed, (see Renwick, 101:) the inside of the boiler is the steam chest.

Your petitioner is of opinion that if the boilers were constructed on the improved plan, and the hydrostat placed upon the middle boiler in the manner recommended in explanations of plate number 2, this hydrostat would so regulate the water that there could be no variation in the quantity of water inserted into the boilers.

To perfect this, the pump, which forces the water into the boilers, should be worked by an engine separate, and in no way depending upon the engine that carries the boat or the works.

When this is done, the engine working the pump should always be kept in motion whenever there was steam sufficient to work it.

The works might be stopped to repair the boat, to wood, load, unload, set out passengers, or repair, and no danger could occur.

Indeed there could no bursting take place, unless the safety-valves were so loaded that seven hundred and ninety-two lbs. pressure to the inch were worked, or nearly eight times as much as is used in any high pressure steamboat, where boilers do not exceed three feet in diameter.

And explosions would be entirely done away under all circumstances.

Your petitioner would represent to your honorable body, that, having spent his substance in the investigation of this subject, which is of the greatest importance to the Government, he has not the means necessary to carry his plan into full operation.

But, unwilling to see his studied and demonstrated plan squandered away in patent rights by unprincipled speculators, he therefore solicits the aid of the General Government, wishing them to furnish means and money sufficient to build a steamboat of 250 tons burden, or a boat of any other dimensions, on the improved plan proposed.

He expects the boat to be the property of the United States.

He wishes commissioners appointed, and would think it advisable to build the boat in the State of Tennessee, as there the materials may be had at the cheapest rate.

He would superintend the building thereof, and furnish the plans for all the castings, projections, &c.

He solicits the attention of the House immediately, and would be much gratified to see his plan fully tested.

If any recommendation as to character is thought prudent before a procedure in the premises, your honorable body are referred to General P. Thomas and Judge E. White, congressmen from the State of Louisiana.

J. O. BLAIR.

Improvements suggested by Joshua O. Blair, which are not to be considered as embraced in the petition presented to the General Government.

First. For safety in boilers already built, when used for working stationary engines, the hydrostat and pump, presented on plate first, should be introduced, and used according to the directions suggested.

Second. When the present form of boilers, now in use, are kept on steamboats, in addition to the hydrostat and pump, there should be a calorometer also introduced.

This is of the figure of a thermometer, open at the top, situated in an iron or brass vase, with the bulb exposed to the direct action of the steam. This should be so constructed that, when the mercury raises or falls, there should be a hand or pointer designating the number of degrees of heat in the boiler.

These are the suggestions which are presented for rendering safe all engines of new construction; and, also, to remedy the evils to which the present constructed boilers are exposed, as far as possible.

The next and last presentation shall be an improvement in the machinery, and the arrangement of the paddling wheels.

The improvements proposed, are a double acting high and low pressured engine in one and the same cylinder.

This arrangement will perfect the greatest application of steam power possible.

The committee of the Philosophical Soeiety of Ciucinnati, appointed to investigate this manner of applying steam power, reported that this arrangement would double the power of the engine at about thirty-eight lbs. pressure, added to the pressure wanted to work a low pressured engine.

A vacuum can be formed under any density of steam.

To make this arrangement perfect, three propelling wheels, one on each side, and one in the stern, would be useful; the cranks of these wheels should be placed at right angles with each other.

These should be propelled by two engines, one on each side of the boat: each engine should be worked with double piston rods, and two connecting-rods.

This would dispense with the fly-wheel, and the line of shafts across the boats.

It would also double the paddling surface.

These improvements I laid before the Legislature of Louisiana in 1825, and to the Philosophical Society of Cincinnati in 1830.

J. O. BLAIR.

N. B. Should the General Government consider this document as embracing facts worthy of attention, it is desired it be printed, and twenty-five copies sent the author.

But, to the contrary, it is desired that the original, with the plates, be returned by Judge White or General Thomas, of Louisiana, in Congress.

Gentlemen engaged in steam machinery are informed that every encouragement will be extended where responsible persons are concerned. It is expected that persons desirous to use any of my improvements will take the trouble to make the usual request for permission. To such, every indulgence will be extended, calculated to benefit those who are hourly exposed to the dangers of the present steam engine.

It has been my intention, before the formality of law was complied with, to mature the machine so far that I could feel safe on board a steamboat: the originality of the design has called out many interests and opinions, some of which have been gratuitously lavished on me and my designs, many of whom, however intelligent on matters of every day's occurrence, have not been considered as having any more knowledge of steam in the abstract, than of the means wanted to counteract an effect of which they have no knowledge of the cause. It is no less true, however, that their opinions, or rather their sayings, have had a baneful influence; so much so, that I have despaired of effecting my object until the evil is of sufficient magnitude to demand the interposition of Government in self-defence of life and property. Then, and, perhaps, not till then, will the steam engine be matured so far as to secure the passenger on board of steamboats.

J. O. BLAIR.

New Orleans, *April the 17th*, 1832.

No. 21.

TREASURY DEPARTMENT,
14*th April*, 1832.

SIR: I have the honor to enclose a communication from Mr. Edward Clibborn, of Cincinnati, relating to the prevention of accidents from the bursting of steam boilers.

I have the honor to be,
Very respectfully,
Your obedient servant,
LOUIS McLANE,
Secretary of the Treasury.

The Hon. C. A. WICKLIFFE,
Ho. Reps. U. S.

CINCINNATI, *April* 3, 1832.

SIR: As all hints and suggestions which may have a tendency to prevent the mischiefs resulting from the bursting of steam "generators," and the sinking of steamers on the western waters, appear to be well received, and attended to in proportion to their merit, permit me to call the attention of our Executive to two very simple plans which I have endeavored, ineffectually, to have added to the steamboat boiler apparatus as furnished from the factories in this place. Before I explain what the apparatus is, I may state that, as far as I have had an opportunity of judging of the causes of the explosions of boilers in steamboats, *two* only have presented themselves as requiring some contrivance to obviate. The first is, the lowness of water in the boilers, and the second is the filthiness of the boilers, arising from a deposite of mud and solid matter from the water on the fire surface of the boilers.

To remedy the first evil, I would propose that a slight change be made in the shape of the gauge cocks, (by which we judge of the water level,) and that small tubes be carried from each gauge cock, and terminated in another set of cocks to be firmly fixed and secured on the right and left of the pilot's house, and within his reach. These cocks to be touched by no person but the pilot. In this way, the pilot would be able to discover the actual state of steam and water, and particularly before starting, immediately after which more than half the accidents have occurred, and all from the consequences resulting from lowness of water. It is objected to this simple arrangement, that such a plan as this would remove responsibility from the engineer, and make him neglect his duty. On the contrary, I believe the same result would follow in this as in every other case, that hirelings are never more on the alert than when they know their idleness and neglect can be, or is, observed by their masters or overseers. The engineer's duty is intermittent on board a steamer. He is not always "wide awake" like the pilot, who, on board a steamboat, as every other kind of craft, is by necessity compelled not only to be wide awake, but have a general eye to the condition of the ship. For this reason the pilot or helmsman, for the time, of a vessel, is bound to notice the sit of sails, the change of wind, &c., and report immediately to the officer in command. An experienced ear and eye can, in a moment, tell by the sound and color of the steam, not only its elasticity, but its tem-

perature; and as pilots generally are far more responsible and respectable people than the general run of the engineers (so called) on the western boats, I really believe that a simple contrivance like this here recommended, would be very useful.

For preventing the mischief resulting from the fire surface of the boiler becoming softened from being over-heated, or scaled off from the same cause, by the formation of a coating of a non-conductor of heat on its inner surface, I beg to submit the following plan, which, though more costly than that just proposed, would, I make no doubt, add to an immense saving in boilers in all situations where muddy, or water containing any of the salts of lime, decomposable by heat, must be used. Boats on the Mississippi and Missouri should consequently be provided with this apparatus. This apparatus is constructed on two principles: first, that water, in a state of rest, will deposite whatever is merely dissolved mechanically in it, and, secondly, that the salts of lime above alluded to are decomposed and precipitated in water (at rest) when its temperature is equal or greater than 212° Fahrenheit. The various contrivances I have seen in England and in America for regulating the water level, have all gone out of order in consequence of the deposite from the water on the valves, floats, and so forth. For this reason I have endeavored to contrive some plan in which none of these things would be used. The apparatus may be thus described: From the larboard and starboard boiler on board a steamer, I would conduct a pipe, the mouth of which must be inverted, which should be so placed as to open at the exact proper level, so that, when the water was at its proper height, the mouth of this tube would be just touching the water. In this case, as the tube would be firmly fixed, its end or mouth would be elevated, as it were, when the water fell or got low; the steam then could pass up and into the tube, which, being inserted into a vessel like a bird's fountain, a supply of water would immediately descend exactly sufficient to fill the boiler to its proper level. This vessel, to which these tubes communicated, should be of equal strength with the boilers. In it one set of gauge cocks would be sufficient; and, as their number and distance from each other might be considerable, the exact quantity of water to supply the engine could be discovered, and any fault in the hot water pump corrected or ascertained before this vessel was completely empty, which could be immediately detected by a drop ceasing to fall from this vessel in some sounding plate, which could be heard by the pilot and firemen. The safety-valve should be fitted to the upper part of this vessel; and when the boilers were long, a tube should pass from each end of the outside ones, or better, from the middle of each of the boilers composing the range. In large engines, the steam and water alternately rushing up and down these tubes, would cause considerable jarring and noise, which could easily be prevented by making the tube double, or having one inside the other, and one a little longer than the other. In this way the water would flow always through the longer, and the steam through the shorter. The supply of steam for the cylinder should be carried from the top of this chamber, and above its water level. A nose should be fitted on each of the tubes carrying the steam from the boilers beneath, to divide the steam, and disseminate it evenly through the water in this vessel, by which means it must always possess its full quantum of water; for, though steam is water in the state of air, yet its elasticity depends in a great measure on its containing a proper proportion of water and heat. It being possible to heat steam to any degree, without at the same time increasing its mechanical effect in the same

degree, as we see the engine stop, or run very slowly, when the boilers get red hot. All the apparatus is the same in an engine with this addition as those now in use, but all the attachments are made to this vessel instead of the boilers. The steam in this vessel decomposes all the salts of lime, and, as these are very ponderable, they would, in a great measure, be deposited in this vessel. To carry this improvement to its highest extent, a false bottom of wood or iron, full of holes, might be fixed in this vessel, on which might be placed some coffee bagging, with some sand on it, which would act as a filterer, and also as a surface for receiving the calcareous sediments, which could be removed with little or no trouble compared with that now required in boilers with flues. The tubes first spoken of might be connected to this chamber or vessel in the same way as if the cocks were placed in the old way.

The other suggestion I propose to offer is to prolong or prevent boats sinking from accidents by snags. The snag chamber is generally so small, or rather steamboat captains and owners are so anxious for freight, that they load their boats so near to sinking, that a small leak, which admits only a ton of water per minute, will sink some of the largest and best boats before they can find a proper resting place, and often before the property of the passengers can be saved. In these cases, the buoyancy of the snag chamber, if uninjured, or the loss of its buoyancy, if full of water, is sufficient to render the specific gravity of the rest of the boat above deck greater than that of water: she consequently must sink. To prevent this evil, and enable avaricious captains and owners to load their boats even above their guard, if they are so foolish as to do so, I suggest the propriety of the handrail being filled up between with thin scantling, like the weather boards on large ships, but that these boards be put together with tongues and grooves. The handrail would thus become a sort of gunwale. The places for cables and lines to run through should be all stopped, and these carried over the rail; the inside of the paddle boxes level with the handrails, and the studding work, round houses, level of seats of privy, and every other opening which could admit water, to be the same, or above the rail. The hatchways to be secured with bars across to prevent the air forcing them up in case the boat were going to sink, and the deck to be made water tight. In this way, a boat, though full of water, in the common acceptation of the term, could swim with perfect safety, the crew and passengers finding little difficulty to *bail her deck* as fast as the water would rise through the numerous little cracks which would no doubt exist. The gangways could have doors sheathed in the same way as the handrail; and as they could be made to fit well, or be caulked on occasion, the whole of the danger to be apprehended from sinking could be obviated in the largest boats for an outlay of perhaps $50 or less. The appearance of the boat would be not much altered, and certainly in hot and wet weather it would be made more comfortable, first, by preventing the reflected light and heat from the water striking the cabin, and, secondly, by keeping out rain and spray, &c.

In the expectation that this hurried communication may be of some use, I remain, your obedient servant,

EDWARD CLIBBORN.

To the Hon. Edward Livingston,
Secretary of State, Washington.

No. 22.

PITTSBURGH, *March* 12, 1832.

SIR: Having taken a very active interest, and paid the greatest attention to the fatal explosions of steam boilers, and made a good many experiments, which led me to trace out the *true cause* which produces the *explosions of boilers*, I went to the city of Washington last month, in the expectation of having an opportunity of giving a full, lucid, and clear statement of the causes which produce explosions; but as the honorable Secretary had not got his report made up, and could not point out when he could bring it before Congress, it induced me to leave that city for this place, where I might have an opportunity of fixing my improvements to some of the boats upon the Ohio river; but, if your honorable body shall think my presence necessary at Washington, I shall esteem it an honor to have an opportunity to explain to the honorable committee my views upon the explosions of steam boilers, with a statement of my improvements which prevents them, with an account of a number of statements which go to prove my theory, by other gentlemen, upon the same. Permit me to state to you, that, in the Franklin Institute of last September, there is two cases recorded by Franklin Peale, which go to prove my statement and theory. He says, "One of our papers, a few months' back, contained a statement of a fact intimately connected with this subject, observed upon the trial of a model engine, and also asked for a solution of the *phenomenon*, which may, I think, readily be given. The statement, if we remember rightly, says, that steam was raised in a small high pressure boiler, the safety-valve of which was raised up by hand, the steam was immediately followed by water, and, ultimately, the whole of the *water* in the *boiler* was *expelled through the valve*. I have frequently lifted the safety-valve of a small boiler, with invariably the same result: water always made its appearance after a brief interval. The solution is easy—a certain quantity of heat is contained in the water of the boiler, which, when the pressure is taken off by the raising of the valve, is sufficient to cause the *water* to *rise in foam*. This is a fact of immense importance in the management of an engine, and yet it is one that was not anticipated by men of science, and of which even practical engineers were uninformed. In company with several engineers, and other gentlemen of science, at a recent trial of a locomotive engine, I was witness to a case exactly in point: it was in action without locomotion, the wheels being raised so as to prevent adhesion; the gauge cocks all indicated water; the engine was stopped; when, to the surprise of those present, *no water was found at the lowest cock*, and no human being could ascertain what was the height of water in the boiler at that time, a circumstance that should never occur, for reasons that every one who has any knowledge of the subject must know and admit." I shall only state one case, which proves my theory: take a quart *tin mug*, and fill it half full of milk, set it upon the fire, and, when it attains to a boiling point, it will rise and flow over; but, if you take a stirer, you will observe the *black smoke rising through the milk*, and the milk will settle down until an aditional supply of steam be formed under the milk, when it will again arise, and flow as before, unless the steam is permitted to escape by the *side* of the *stirer*, which is very visible, being black and *rarefied*. It is the same in a boiler: the steam propels the water from the heated metal, when the pressure is taken off the upper surface of the water. I will

have an opportunity, in a short time, to convince the public this is the only remedy which can prevent explosion; but it would come with more grace and confidence from your honorable body to the public, than from your very

Humble and obedient servant,

JOHN C. DOUGLAS.

To the honorable Charles A. Wickliffe,

Chairman of the Select Committee on the subject of Steamboat Navigation, and the Bursting of Boilers.

P. S. If the report is printed, please forward a copy to Pittsburgh for me, and oblige,

Sir, yours respectfully,

J. C. D.

No. 23.

Sir: A hydraulic forcing pump, of sufficient capacity for proving the strength of a steam boiler, so constructed as to be portable, and, at the same time, applicable to every description of boiler, can be manufactured in Cincinnati, Ohio, for about three hundred dollars:—the entire operation can be moved from place to place, and from one boat to another, on a common wheelbarrow.

The inspection can be made, at most, in three hours, by the labor of two men. It can in all cases be made when the boat is in port engaged taking in or discharging cargo; consequently, no delay will take place in the business of the boat.

Your obedient servant,

H. M. SHREVE.

Honorable C. A. Wickliffe.

No. 24.

Cincinnati, Ohio, *October* 30, 1830.

Dear Sir: Permit me to trouble you with a letter relative to a bill which you reported last session of Congress on the subject of steamboats. The numerous explosions which have happened in the last twelve months are alarming, and almost a sufficient cause to deter a man from travelling in this way; though I think these fears may be suppressed by the intervention of Congress.

It was with pleasure that I saw you manifest some anxiety for devising a plan which might prevent the untimely death of many of our fellow beings; for nearly one hundred persons have fallen victims to that tremendous agent, steam, in the course of two years. Many of these accidents, I am very certain, arise from the incompetency of engineers; for, it is very evident, if a man has not some mathematical knowledge, understands some chemistry, also hydrostatics and hydraulics, he cannot make those neat calculations of the pressure of steam, and know the strength of the materials that compose an engine, neither can he tell the cause of the different effects. There is a law now in England, and has been for many years, I believe, that prohibits a man from being an engineer unless he can bear an examination, and this is

one cause why scarcely an accident has happened there since 1817, when this law passed. This subject will be before Congress this session again, I suppose, and I hope you will use your influence in effecting the passage of a similar law, for there are now a great number of men engaged and engaging in the engineering business, through the influence of their friends and relatives, who are no mechanics at all, and scarcely know any thing about either theory or practice; and as long as this course is pursued and allowed, so long will man be blown into eternity. It frequently happens when boats come in contact, racing, that some engineers, entirely ignorant of danger, overload the safety-valve, thereby exposing to hazard the lives of hundreds. As to the number of pounds of steam that the safety-valve should be limited to, must be in proportion to the strength of the boiler, and as to the number that this should be, I am not prepared to say at present, but I expect what you stated in your bill is nearly right, though I shall consult some experienced engineers on this subject, and you shall hear from me and others after you shall have arrived at Washington.

Some of the explosions that have taken place have been ascribed to a chemical cause, which I have no doubt is correct; though this can never take place only when the engineer neglects his business, and lets the water in the boilers get below the top of the flues, for then the naked flues are exposed to the action of the fire; consequently, the steam, exposed to the heated surface of iron, becomes decomposed, and resolves itself into its elementary principles, oxygen and hydrogen. The oxygen unites with the iron, and the hydrogen, from its lightness, takes the upper part of the boiler, and as it increases in bulk in proportion to the surface of heated iron, it must, from necessity, so far fill the boilers as to arrive eventually at the heated flues, where it would again be forced in close contact with the oxygen it had surrendered to the iron at the time the hydrogen was formed. The oxygen, then, being a great supporter of combustion, takes fire, and explodes with great violence.

There was a gentleman by the name of Joshua O. Blair here last spring and summer, who invented a new plan of a boiler to prevent explosion from a chemical cause, by carrying the boilers full of water, with a separate reservoir for the steam. His plan I think highly of. He left here about three months ago, and said he would probably see you, as he wanted to try and get some support from Congress for putting his plan in execution. I wish to know of you whether you saw him: if not, I expect he has gone on to Louisiana, where he told me he thought he would be assisted by the Legislature of that State. I wish to know of you, also, before you leave home, whether any persons have written to you from Louisville on this subject, as that is my home, though I have been here about one year, for the purpose of gaining all the information I could relative to the steam engine; and as Cincinnati is famed for building good engines, and for good mechanics, I have been favored with every opportunity I wanted. I will mention to you, that it is the boiler heads that generally give way at the time of explosion. These heads are of cast iron, and I believe there is but one single instance, since steamboats started on the western waters, of a wrought iron head giving way, and this was owing to the imperfect manner in which it was made. Wrought iron will bear seventy-two thousand pounds to the square inch, and cast iron only seventeen thousand pounds to the square inch: so I think it is certainly evident that cast iron heads should be prohibited by law. It is true they can be cast very thick, and they may look sound on the external surface, when, at the same time, the internal part is

very defective: this has been proved at the expense of many lives. I am engaged in Robert C. Green's engine shop, where I shall continue probably all winter, and if you pass here on your way to Washington, I should like very much to see you, provided your stay would justify your walking up to the shop, which you can find with little trouble.

I am sincerely yours,

THOS. J. HALDERMAN.

CHAS. A. WICKLIFFE.

No. 25.

SING SING, *April* 4, 1832.

MY DEAR SIR: I received yours, and its accompanying circular of the late Secretary, Mr. Ingham, respecting engines, and should have written you before this, but I have been quite unwell.

I am not, it is certain, of the class of persons that he has addressed, but having some knowledge, as you know, on the subject, both theoretical and practical, I would freely add my mite to the general stock of information: and it has fallen in my way to know, by actual information, *one fact* having a material bearing on the subject, which is, that the product of steam or the vapour of water at a high temperature in the boiler, *is actually inflammable.*

The particular circumstance that I have stated occurred with the trial engine I constructed here some years ago for high rarefied steam, or, perhaps I might say, its elements. On one occasion, when it was working the blast, there was a sudden falling off in its power; the service pump, the stuffings, the valves, the joinings, (the piston was a metallic one, the first, I believe, made in this country,) every thing appeared in proper order; still the energy of the engine was gone. Finally, upon examining within the furnace, I found a *blue lambent flame burning* from about six inches of the upper turn of the service pipe from the pump which passed through the furnace, and which continued to burn till the pressure was reduced. The ordinary pressure, and which it had been working under, was about 75 lbs. to the inch. At a pressure of 200 lbs., which I sometimes had it up to, if the lowest of the gauge cocks, which was level with the bottom of the under boiler, was opened, nothing but a strong blast (that the hand might be held to) came out, and would continue until the boilers were exhausted: a light brought within its action was from its force blown out as by a bellows. But, in the case I have related, when it issued through a minute fissure, as the crack proved to be, into the heated furnace, it ignited and flamed. Of the theory of the ignition, whether the oxygen of the vapour at once served to the combustion of the hydrogen, or separated from it in the heated furnace, may possibly by some be open to inquiry; but the application will not be altered. Berthollet, I think it was, many years ago, assumed that water would decompose at a high temperature, and since, other scientific men of high standing; but latterly I have observed statements asserting the impossibility of decomposition in the boiler, made doubtless from a limited knowledge of the subject, or a mistake as to the formation of water from its elements by compression; thence inferring that, under pressure, water will not decompose. This may be a play upon the term, or narrowing its signification short of the compass given it by scientific men. If water is reduced to its elements by caloric, or by heat, it

may be termed decomposed, though those elements may not be separated. I should remark, that the boilers were cast iron cylinders, two inches thick, one for water, the other for steam, set in a brick furnace.

In the interrogatories, I do not see any notice of the mercurial gauge, considered so prominent an agent, by showing the pressure within the boiler of the low pressure engine. This is certainly a very important part, and has immediate bearing on the subject. I have noticed it from the circumstance of the inverted siphon shewing but one-half of the true rise of the mercury; that is, when one inch is shown on the index, two inches are actually raised.

Mr. Banks, who first proposed its use, applied it barometrically to the cylinder to ascertain the density of the uncondensed vapour. The best engines noted in his experiments condensed to 2¼ inches; the boilers of such engines could scarcely, by any possibility, explode, as they could perform their work under so light a pressure, probably 1½ to 2 lbs. It has often appeared to me that there should be some fixed rule (legislative perhaps) to determine the appellation of low pressure engine from the positive or high. An engine that requires more than half an atmosphere to make up for imperfect condensation, should not be called low pressure. A regulation to this effect would bring the pressure on that class of boilers to 7½ or 8 lbs—take 9 lbs. for the maximum: it would only require a little more skill in the construction to condense more perfectly, and apportion the induction to overcome the vis inertiæ of the piston.

I shall be pleased to see the documents, when printed, if convenient to send them; for, as I have before said, I am satisfied the means are simple for preventing nine out of ten of the accidents.

I am, my dear sir, yours very truly,

GEO. W. CARTWRIGHT.

Hon. Aaron Ward.

No. 26.

Philadelphia, *June* 7, 1832.

To the Committee of the House of Representatives of the United States, appointed to examine into the causes, and to devise means for the preservation of, the explosion of Steamboat Boilers:

Gentlemen: The subscriber has had a long experience in the construction and arrangement of machinery, having been a practical engineer, engaged for more than thirty years in the design and building of steam works, gas works, and furnaces for the application of heat to a great variety of purposes, including those of nearly every species of manufacture. During this period, he has had opportunities of observing the operation of steam apparatus of all descriptions; he has carefully noted their several advantages and defects, and has devoted particular attention to the causes of steamboat explosions. He believes it unnecessary to recapitulate those causes, as, in the cases which have fallen under his own observation, they have been fairly referrable to some one of the six general heads reported by the committee. The undersigned will merely remark the great importance which he attaches to the construction of boilers employed in steamboats. These, he conceives, should be peculiarly adapted to the service in which they are

used, and essentially different in construction from those employed in stationary apparatus; to the mode of feeding the boiler, in which he believes he can suggest important improvements; to the provision of proper and sufficient vacuum valves; to the entire security of the engine from the attempts of rash and ignorant engineers, or others, to alter its action, or experiment with its powers; and, finally, to the monthly examination, by a competent engineer, of every working engine, and particularly into the state and cleanliness of the boiler.

After a thorough examination into the defects of existing engines, the undersigned has succeeded in the construction of an apparatus, the use of which will, he is satisfied, prevent, as far as that is possible, an explosion from any of the causes suggested by the committee; and he is willing to stake his professional character upon the result of a fair experiment of its action and powers.

The following are some of the advantages which characterize the invention of the writer.

1st. The boiler promptly relieves itself from any vacuum, as well as from the pressure of surplus steam when generated in greater quantity than required for the purposes of the engine; and this, in such a manner as to be beyond the control of persons employed about the engine.

2d. The boiler is always regularly supplied with water, in the proportion of its consumption, so as to maintain a steady average depth.

3d. The depth of water in the boiler is exhibited in such a manner as to show the quantity at all times, as well as the mode of supply, the discharge of surplus, &c.; so that if the pump misses a single stroke, from the adhesion of its packing, or any other cause, it will be at once observed. And surely nothing can contribute more to the safety of all concerned than a constant view of the exact quantity of water contained in the boiler.

4th. The flues constructed by the subscriber are adapted to the consumption of any kind of fuel, as the owners may desire.

The writer will only add, that the effectiveness of his apparatus does not rest upon conjecture; nor its utility upon the beauty of a fine drawing or elegant model. On the contrary, it has been submitted to the test of experiment, and has been long used, in all its parts, under the eyes, and to the entire satisfaction of himself and sons.

The object of this communication is to make known to the committee the existence of this apparatus, and to ascertain whether any sufficient protection to his rights can be secured by the inventor; or if Congress will confer upon him any remuneration, upon condition that he shall, after a sufficient experiment, under such superintendence, practical and scientific, as may be judged proper, publish his plans, and give up his invention to the public.

Of the inutility of the present patent laws, the writer has had ample proof, in the case of an improved steam kitchen range, of which he is the inventor and patentee; the principle of which has been pirated, and since re-patented by another person, from whom the subscriber can obtain no redress, although he has sought it at considerable expense. Indeed, his experience induces the belief that no patent is worth taking out, unless the patentee can spare a few thousand dollars to defend his rights under it. These considerations have hitherto restrained the undersigned from bringing forward this invention, although it has been completed several years. The machinery which is the subject of this communication, is so simple that almost any mechanic, knowing something of the power and application of steam,

might, after a single inspection of the models, erect a similar apparatus, and thus deprive the inventor of any chance of adequate remuneration. All which is very respectfully submitted by the committee's obedient servant,

JOHN LOVATT,

No. 316, North 3d street, Philadelphia.

An answer to this communication is respectfully asked by the writer.

No. 27.

EXPERIMENTAL INQUIRIES

Respecting Heat and Vapor; with some practical applications: by Walter R. Johnson, Professsor of Mechanics and Natural Philosophy in the Franklin Institute, Philadelphia.

To account for the sudden explosions which sometimes occur in steam boilers, one hypothesis assumes that the metal, by undue exposure to the fire, and by a deficiency in the supply of water, becomes intensely heated, and thereby affords a *source of heat* ready to act with great rapidity on any new portion of water which may be injected, or otherwise brought into contact with the heated surface. Whether the water be thrown up by ebullition, or caused to flow over the hot part of the boiler by some *change in the position* of the latter, will be of little consequence to the result, so long as we are sure of the presence of the dangerous generator.

The construction of many steamboats, or rather the arrangement of their boilers, favors the presumption that a mere change of position has sometimes caused an explosion of the nature now alluded to.

In the boats which navigate our western waters, eight or nine boilers of a cylindrical form, thirty inches in diameter, and about fourteen feet long, are laid side by side, lengthwise of the boat, so that, allowing for interstices, from twenty-two to thirty feet of the breadth of the deck are taken up by the aggregate diameters of the row of boilers. They are almost uniformly constructed with *returning flues*, from nine to twelve inches in diameter.

The flue being placed eccentric with respect to the main cylinder of the boiler, and indeed wholly below its centre, will be entirely immersed when the boiler is half filled with water. The furnace being at one end, the flame passes along the whole length of the boiler on the outside, and then, entering the flue, returns to a chimney near the upper or *fire* end. The boilers are all connected together by a pipe forming a water communication at bottom, and by another forming a common steam passage above their upper surfaces. The lower gauge cock is placed from one to three inches above the top of the flue; and so long as the deck remains pefectly horizontal, and the forcing pump for injecting water performs its office, a moderate degree of care, on the part of firemen and engineers, may insure the complete immersion of the flue. But when, from any cause, the boat inclines to either side, there will be a transfer of water through the lower connecting pipe, from the boilers on the elevated, to those on the depressed side of the deck. A large number of passengers collecting on one side would doubtless be sufficient to cause a "heeling" of a foot or more, and this would lay bare the whole of the flue in the upper boiler, and expose more or less surface of iron in every flue and boiler on the elevated side. Every pound of water thus

transferred, serves to increase, by double its own weight, the tendency of the boat to *careen*, and even after the other causes of unequal depression have ceased to act, the water thus displaced will continue its influence, and will not, until after some time, return to its former level through the pipe of communication. The removal of water from the part of the usual generating surface of metal, will cause the supply of steam to be diminished, so that the *engine* may appear to labor, even while the boiler is becoming red hot. This circumstance is known to have preceded some of the most frightful explosions, and it is but the natural result of employing that caloric which ought to be producing steam, in merely raising the temperature of metal, with the incidental effect of heating the steam already generated considerably above the temperature which belongs to its actual *density*. Not only must those parts of the boilers and flues which are immediately exposed to the fire, become unduly heated, but, owing to the high conducting power of the metal, the upper arch of the cylinder, as well as the lower, will rapidly acquire the temperature due to the source of heat. Some may possibly imagine that, since the engine moves slowly for a time in consequence of a deficiency of generating surface, it will only move with the more speed when the accumulated force comes to be added to the regular supply. This might be the case if the excess were furnished with no greater rapidity than the deficiency had occurred. But whether we suppose the hot steam or the hot metal to furnish heat of elasticity to the water which flows into the over-heated boilers, the supply will be obtained almost instantaneously;—a few seconds, at most, being required to complete the operation of generating, from water of a boiling temperature, all the steam which the iron of the boiler, even when red hot, is capable of producing. In order to determine, with some precision, what effect will actually be produced by the metal in such cases, I have performed a series of experiments tending to show the relation between the quantity of steam generated, the weight of the metal, the surface exposed, the time of action, and the period of greatest effect. The trials have not been confined to rolled iron alone, but, as the results must obviously be effected by the *specific caloric* of the metal, I have extended them also to wrought iron in masses, to cast iron, copper, brass, silver, and gold.

These experiments were in part performed during the months of July and August last, when the temperature of the room seldom fell below 80°. This circumstance may, in addition to the other precautions to avoid error in the results, assure us that the change of temperature in the water, between two consecutive experiments, cannot, at any time, have been sufficient to affect the *quantity* of vapor generated, or the *time* employed in its production. In order to exhibit an approximation to the actual state of the boiler, when in a condition to receive hot water on intensely heated metal, and when, of course, the whole excess of caloric would be employed in giving the elastic form, and none in raising temperature, I procured a cylindrical vessel of tinned iron 19¼ inches deep, 7 $\frac{2}{10}$ inches in diameter, and capable of containing 28$\frac{5}{16}$ lbs. of water at 60°. This was furnished with a cover of the same material, and with a wire handle like that of a bucket, for the convenience suspending it to the beam of a pair of scales. The sides and bottom were covered externally with four successive folds of stout green baize, between each two of which was a *batting* of raw cotton, forming altogether a coat of an inch thick. The non-conducting character of this defence may be inferred from the fact that fourteen pounds of water, left in the vessel for fourteen

hours, was cooled only from 212°, to 115°, or about 7° per hour, while the temperature of the apartment was 80°; and that, in the following twenty-five hours, the same portion of water lost only 31°, being found at 84°, though the temperature of the air had in the mean time fallen to 76°. On another occasion, the loss was 9° per hour, or from 212° to 104° in twelve hours, in an apartment where the air was at 60°.

The vessel above described, charged with about 15 lbs. of water, was suspended to one hook of the scale beam, while to the opposite was attached the usual pan for weights. The water was then brought to a state of rapid ebullition by heaters, previously plunged for an instant into another vessel of water, to take off any portion of ashes or oxyde which might accidentally adhere to the surface. When assured that the water and its container had acquired the boiling temperature, I replaced the cover, and immediately adjusted the weights to an exact counterpoise. The piece of hot metal whose power of producing steam was to be ascertained, was, upon removing the cover, immediately plunged into the boiling water, and permitted to remain until ebullition ceased. At that instant, the metal was withdrawn, the time noted, the lid adjusted, and weight added on the side of the boiler, to compensate for the evaporation of water, until the equilibrium was restored. The experiments were conducted with all due caution, to avoid the waste of water which might ensue from the violent agitation caused by plunging the metal all at once below the surface. The metal was either lowered gradually into the water, or, when plunged in immediately, was suspended to a wire; attached above to a cover, perforated with numerous holes, to allow the escape of steam, and furnished with a broad funnel shaped rim to receive and return any water which might be projected through the apertures.

In order to avoid communicating to the apparatus a temperature above that of the liquid, the metal was suspended in the water, and not allowed to touch the sides or bottom of the cylinder.

The difficulty of ascertaining with precision the temperatures above the boiling point of mercury, (660°) compelled me to adopt as a standard of comparison between the different metals, and between different masses of the same metal, a point indicated by the senses. *A barely red heat in daylight* was chosen as least liable to be misapprehended. Many experiments have been made at temperatures both above and below this point; but, as it is probable that the heated part, of boilers are seldom raised above a dull red heat, and that, if they were so, their danger, or (perhaps we might say) their *safety*, would arise from the softness and yielding condition of the metal, it has been thought that, for practical as well as theoretical purposes, the point above mentioned would be most interesting and important. The experiments to determine the period of *greatest activity* will show, that, just below the point of visible redness in daylight, the greatest quantity of steam is generated in a given number of instants. Such at least is the case when the experiment is performed under ordinary atmospheric pressure. This point, therefore, I have termed in the tables the *comparable temperature*. Many of the experiments with wrought iron were performed upon a piece of rolled boiler *plate*, 25½ inches long, by 7½ broad, and $\frac{3}{16}$ of an inch thick, affording a surface (including both faces, and all the edges) of three hundred and ninety-five square inches. This was reduced to a coil, for the greater convenience in managing the experiments, but sufficient space was left for the free admission of water to every part of the surface. The first series was intended to exhibit the *quantity* of steam

generated without particular reference to the time. The latter, however, was immediately noted on each occasion, but is not to be taken as the *least* time in which the mass of metal employed could impart its surplus heat to boiling water. It serves to show that no essential difference was discoverable in the amount of steam produced by metal of the same temperature, whether the latter were immersed all at once, or only covered by degrees with the water; and that, consequently, the portion of over-heated surface which remained above the water, did not impart to the steam which ascended any appreciable quantity of its caloric, during the experiment.

FIRST SERIES,

With rolled iron, 395 square inches of surface—water at 212° Fahrenheit; barometer 29.9 inches; the time marked by a pendulum beating seconds: temperature of the apartment from from 80° to 85°.

No. of experiment.	Weight of metal in ounces avoirdupois.	Time in seconds.	Weight of steam in ounces avoirdupois.	Decimal part of an ounce of steam from each ounce of metal.	No. of ounces of metal that produced each ounce of steam.	Observed heat of the metal in day light.
1	144.	40	10.75	.0746	13.395	Black heat.
2	144.25	90	16.	.1109	9.016	*Comparable* or dull red in day light.
3	144.25	90	16.	.1109	9.016	*Do.* do. do.
4	144.125	90	16.	.1110	9.008	*Do.* do. do.
5	144.125	90	16.	.1110	9.008	*Do.* do. do.
6	144.	70	16.5	.1145	8.727	Slight incr'se in redness, plunged sooner.
7	144.	150	19.75	.1371	7.291	Clear red, immersed by degrees.
8	144.25	120	20.	.1386	7.2125	Bright red.
9	144.	90	21.	.1458	6.857	Brighter red.
10	144.	90	22.5	.1562	6.400	Very bright; metal yielding easily.

The 2d, 3d, 4th and 5th experiments, present a remarkable coincidence of results, and prove that, at the temperature of comparison, nine pounds of wrought iron will generate one pound of steam under atmospheric pressure. Subsequent series will show that, but for the caution necessary to avoid waste, this effect might have been produced in twenty-five or thirty seconds, instead of the times above noted.

SECOND SERIES,

With wrought iron cylinders, 6 inches long, and 1.7 inches in diameter; surface, 38 square inches, including that of the hook: water kept at 212°.

No. of experiment.	Ounces avoirdupois of metal.	Time in seconds.	Ounces of steam produced.	Decimal part of an ounce of steam to one ounce of metal.	Ounces of metal for each ounce of steam.	HEAT OBSERVED.	REMARKS.
1	62.5	42	4	.0640	15.625	Black.	Iron immersed at once.
2	62.5	45	4	.0640	51.625	Do.	Do. do.
3	62.5	45	5.25	.0840	11.904	Do.	Do. do.
4	62.5	48	5.5	.0880	11.363	Do.	Do. do.
5	63	120	7	.1111	9.000	Dull red; comparative temp.	Do. by degrees.
6	63	120	7	.1111	9.000	Do.	Do. do.
7	63	120	7	.1111	9.000	Do.	Do. do.
8	63	120	7	.1111	9.000	Do.	Do. do.
9	63	80	7.25	.1150	8.689	Do.	Do. quickly, but not *at once.*
10	62.5	90	7.75	.1240	8.064	Fair red.	Do. do.
11	63	150	8	.1270	7.875	Do.	Do. by degrees.
12	63	150	8	.1270	7.875	Do.	Do. do.
13	62.25	100	9.5	.1365	6.552	Full red.	Do. at once.
14	62.25	120	10.5	.1686	5.928	Bright red.	Do. do.

The striking correspondence in the results of those experiments in the above series which purport to have been made at the *comparable temperature* (No.'s 5, 6, 7, 8 and 9,) with the analogous ones in the *first series*, render it evident that, in this form as well as in that of the plate, the amount of steam generated by any portion of wrought iron at a dull red heat, bears a direct relation to the weight of metal, being one pound of steam to every nine pounds of iron.

THIRD SERIES,

With cylinders of cast iron of different weights, and at different temperatures; water at 212°. The surface exposed in each experiment, is indicated in a separate column.

No. of experiment.	Weight of metal employed, in ounces.	Time in seconds.	Ounces of steam produced.	Dec. part of an oz. of steam to 1 oz. metal.	Ounces of metal to 1 of steam.	Square inches of surface.	HEAT OBSERVED.	REMARKS.
1	60	30	2.25	.0375	26.666	37.69	Black.	Immersed at once.
2	168	60	6.75	.0401	24.888	86.25	Do.	Do. do.
3	152	80	7.	.0460	21.714	77.47	Do.	Do. by degrees.
4	60	50	3.375	.0562	16.000	37.69	Do.	Do. at once.
5	168	90	14.25	.0848	11.789	86.25	Do.	Do. do.
6	152	135	13.75	.0904	11.054	77.47	Do.	Do. do.
7	60	55	5.5	0916	10.909	37.69	Do.	Do. do.
8	60	55	5.5	.0916	10.909	37.69	Do.	Do. do.
9	168	105	15.5	.0922	10.838	86.25	Do.	Do. do.
10	168	106	16.	.0952	10.500	86.25	Do.	Do. do.
11	60	60	6.5	.1083	9.230	37.69	Low red in the dark.	Do. do.
12	60	55	6.75	.1125	8.888	37.69	Do.	Do. do.
13	60	55	6.75	.1125	8.888	3·,69	Do.	Do. do.
14	61	90	7.	.1147	8.714	37.69	*Comparable*, (dull red in day light.)	Do. by degrees.
15	168	300	19.5	.1160	8.618	86.25	Do.	Do. do.
16	168	300	19.5	.1160	8.618	86.25	Do.	Do. do.
17	61	105	7.25	.1185	8.413	37.69	Do.	Do. do.
18	61	105	7.5	.1229	8.133	37.69	Do.	Do. do.
19	61	120	7.5	.1229	8.133	37.69	Do.	Do. slowly.
20	152	300	19.	.1250	8.000	77.47	Do.	Do. do.
21	152	300	19.	.1250	8.000	77.47	Do.	Do. do.
22	152	300	19.	.1250	8.000	77.47	Do.	Do. do.
23	60	70	7.75	.1291	7.741	37.69	Brighter red.	Do. almost instantly.
24	152	300	21.	.1316	7.238	77.47	Clear red.	Do. gradually.
25	61	90	8.	.1331	7.625	37.69	Do.	Do. in few seconds.
26	61	120	8.5	.1393	7.176	37.69	Do.	Do. gradually.
27	168	180	23.5	.1398	7.149	36.25	Full red.	Do. do.
28	60	75	8.5	.1416	7.058	37.69	Do.	Do. at once.
29	151	300	22.	.1457	6.864	77.47	Do.	Do. gradually.
30	61	120	9.	.1475	6.727	37.69	Bright red.	Do. do.
31	152	180	29.	.1908	5.241	77.47	Do.	Do. in few seconds.
32	60	105	11.5	.1916	5.217	37.69	Very bright.	Do. rapidly.
33	152	270	32.75	.2154	4.641	77.47	Do.	Do. gradually.
34	152	360	34.	.2237	4.470	77.47	Do.	Do. slowly.

It appears from the preceding table, that the least amount of steam given by any of the experiments, was that of No. 1, where, under the head of *decimal parts*, we find $3\frac{3}{4}$ per cent.; and the greatest amount was that of No. 34, where the same column exhibits $22\frac{37}{100}$ per cent. In the latter case, $4\frac{47}{100}$ lbs. of metal gave a pound of steam, while, in the former, $26\frac{2}{3}$ lbs. were required for that purpose.

A comparison of the third series with the two preceding, will show that, at the *comparable temperature*, cast iron is capable of generating more steam for each unit of weight in the metal, than wrought iron. It may possibly be found that the temperature of *luminousness* in the two kinds, is

different. But, from heating similar masses of the two, side by side in the same exposure, and observing no difference in the time of coming to redness, I have been led to attribute the difference to a difference in the specific caloric of cast and wrought iron; a circumstance which would probably be sufficiently accounted for by the difference in their constituent elements.

The mean amount of cast iron to each pound of steam, in the nine experiments marked *comparable*, is $8\frac{281}{1000}$ lbs. We might probably assume $8\frac{1}{4}$ as the number, without material error.

From the data above furnished, we may readily calculate the quantity of steam, of atmospheric pressure, which would be generated by any known quantity of iron that should become red hot. Thus, should a boiler twenty feet long and thirty inches in diameter, with a returning flue one foot in diameter, be constructed of iron one-fourth of an inch thick, the exterior shell would give a curved surface of 157 square feet, and, as the specific gravity of good boiler iron is 7.770, it must weigh 10 pounds 2 ounces to the square foot. The whole exterior cylinder would therefore weigh 1582 pounds, exclusive of any allowance for rivets and for double thickness at the joints. The weight of the interior shell or flue will be 636 pounds. As the fire is supposed to act on *one half* of the outer shell, and on the *whole* of the flue, there would, in case of the heeling of a boat sufficiently to throw all the water out of one boiler, be no less than $636+\frac{1582}{2}=1427$ pounds of iron exposed to the direct action of the fire, and liable to become red hot. By the *first series*, we see that one pound of atmospheric steam will be generated from water at 212° by every nine pounds of iron, at a low red heat, in day light; consequently, the metal above supposed would be sufficient to produce $\frac{1427}{9}=158\frac{5}{9}$ lbs. of steam from water at 212°, whenever a change of position should favor its influx in sufficient quantity to cover, either by actual submersion, or by violent agitation, the surfaces of the flue and lower arch of the boiler. To calculate the effect of this weight of vapor, we must compare its bulk with the *steam-room* left in the boiler. The whole interior capacity of the latter is but 82.4 cubic feet; but, in the condition of things now supposed, a small part only of this space is occupied by water.

The bulk of steam becomes known by comparing its specific gravity with that of the water from which it is formed. Thus, assuming the specific gravity of common air, at 60° Fah. to be .00122 of that of water at same temperature, as determined by Biot and Arago, the specific gravity of steam compared with air at 60° being .481 to 1, the specific gravity of steam compared with *water at that temperature*, is .00058682. As $158\frac{5}{9}$ lbs. of water at 60° measure $\frac{158.5}{62.5}=2.536$ cubic feet, the *atmospheric steam*, which can be obtained from it will be $=2.536\div.00058682=4321$ cubic feet; which, divided by the capacity of the boiler, gives $\frac{4321}{82.4}=52\frac{362}{824}=52\frac{3}{7}$, nearly, for the number of atmospheres of pressure, supposing the whole to be condensed and confined in the sigle boiler, within which we have shown that it may be generated. This would give 786 lbs. to the square inch. But upon the

supposition that, while heat continues to be applied to the boiler, from which the water is drained, its connexion with others remains uninterrupted, nearly the usual pressure will be maintained within it. This pressure may be stated at 8 atmospheres; so that by adding the $52\frac{3}{7}$ derived from the over-heated metal, we should have no less than $60\frac{3}{7}$ atmospheres or 906 lbs. to the square inch for the resulting elasticity. This is upon the assumption that steam obeys the same law in regard to its relative bulk and elasticity, as that which governs atmospheric air. But if it do not follow that law, there is no probability whatever that the pressure would be less than in the direct ratio of the density.

It is true, that if only one boiler in a range were to become empty and exposed to excessive heat, at the same time the quantity of steam just calculated would be, in part, distributed through the connecting pipe to the others, at the moment of its production, which would diminish, in a measure, the pressure in the over-heated boiler: it may be said, on the other hand, that the over-heating of the outer shell will never be confined to the lower arch, nor to a single boiler in a range; and it is evident that the lower boilers in a boat, must, in the cases supposed, want *steam room* in proportion as the upper want water; and that the connecting pipe could not, as generally constructed, convey away the steam so fast as it would be produced. The boiler which had been most remote from the wharf, has generally sustained the injury in explosions that have occurred immediately after putting off.

Before proceeding to the detail of experiments on other metals, I think it proper to present the following series of results, in which my main object was to ascertain, accurately, the rapidity of cooling of iron from incandescence down to 212°, taking into consideration the temperature of the water both at the beginning and end of the experiment, its weight in some cases, and the relation, in all cases, between the weight of metal and the amount of its generating surface. These experiments were performed in an apparatus similar to that described in my former communication, but furnished with an attached thermometer, to mark, with accuracy, the temperatures attained. The result, as it will be seen, is, that the times approximate to an inverse proportion to the generating surface. This proportion will not be found to obtain, where part of the heat was employed in raising temperature, and a part in generating steam. The time demanded for cooling a given mass of metal from redness to 212°, by the latter process, must be greater than by the former, both because the temperature of the liquid, which is to receive heat, is greater, and the difference between it and the metal less, and because the surface of the iron is momentarily denuded of water, and prevented from acting by a constant and uniform communication. The temperature, in a few instances, was calculated by multiplying the weight of water by the number of degrees through which it was heated, and dividing the product by the weight of metal multiplied into its specific heat. To the quotient was, of course, added 212°, the temperature at which the metal was withdrawn after every trial.

FOURTH SERIES,

Showing the time in which iron, in a state of incandescence, may be reduced to the boiling temperature, either by heating water from different points, by generating steam, or by both operations in succession.

Quality and form of the masses of metal.	No. of experiment.	Weight of water.	Relation of *surface to weight* of metal.	Temperature of water at the beginning.	Temperature attained at the end.	Time in passing from incandescence to 212°.	Calculated temperature.	*Remarks on observed temperatures.*
		lbs.	*oz. sq. in.*	°	°	″	°	
Cast iron cylinder, 168 oz. 86.25 sqr. in.	1	26	1 : .513	60	138	77	1805	Very bright red.
	2	unc.	1 : .513	60	140	81	-	Comparable.
	3	unc.	1 : .513	120	212	71	-	Clear red.
Cast iron cylinder, 150 oz. 77.25 sqr. in.	4	15	1 : .515	55	190	126	-	Bright red.
	5	21.5	1 : .515	60	144	117	1801	Very bright red.
	6	unc.	1 : .515	60	212	114	-	Bright red.
	7	11	1 : .515	76	180	95	1218	Above comparable.
Cast iron cylinder, 60 oz. 37.5 sqr. in.	8	unc.	1 : .625	60	100	90	-	Very bright.
	9	10	1 : .625	80	212	112	-	Do.
	10	unc.	1 : .625	212	212	128	-	Very bright, continued red in the water 82″, and ebullition ceased in 46″ afterwards.
	11	14	1 : .625	180	212	110	-	Bright.
Rolled plate of wr't iron 3-16 in. th'k, 144 oz. wt. 395 sq. in. surface	12	Quantity of water not observed.	1 : 2.75	60	212	23	-	Comparable.
	13		1 : 2.75	100	212	23	-	Do.
	14		1 : 2.75	128	212	33	-	Full red.
	15		1 : 2.75	175	212	41	-	Bright red.
	16		1 : 2.75	180	212	25	-	Comparable.
	17		1 : 2.75	212	212	25	-	Do.
	18		1 : 2.75	212	212	28	-	Do.
	19		1 : 2.75	212	212	36	-	Full red.
Cylinder of wr't iron weighing 16 oz. and comprising a surface of 18.2 square inch.	20	1.375	1 : 1.14	32	133	20	1462	Clear red.
	21	1.375	1 : 1.14	40	127	19	1288	Rather less red, but above comparable.
	22	1.375	1 : 1.14	72	172	21	1449	Clear red.
	23	1.375	1 : 1.14	100	212	25	-	Do.
	24	1.375	1 : 1.14	112	212	30	-	Do.
	25	1.375	1 : 1.14	126	212	31	-	Do.
	26	1.375	1 : 1.14	148	212	36	-	Do.
	27	1.375	1 : 1.14	168	212	43	-	Do.
	28	1.375	1 : 1.14	190	212	75	-	Do.
	29	1.375	1 : 1.14	200	212	77	-	Do.
	30	1.375	1 : 1.14	212	212	78	-	Do.

FIFTH SERIES,

With hollow cylinders of copper, presenting 149 square inches of generating surface—water kept at 212°.

No. of experiments.	Weight of metal in ounces avoirdupois.	Time, in seconds.	Ounces of steam produced.	Decimal part of an ounce of steam to each ounce of metal.	Ounces of metal to each ounce of steam.	Heat observed.	Remarks.
1	158.50	75	9.875	.0636	16.050	Black	
2	158.25	50	10.5	.0663	15.071	Do	
3	157.	70	12.25	.0780	12.816	Ruddish by dusk, but not in day light	
4	159.	70	13.5	.0846	11.777	Do	
5	159.25	73	14.25	.0895	11.175	*Comparable* dull red	
6	159.	45	14.25	.0896	11.158	Do	Immersed at once.
7	158.	55	14.5	.0911	10.896	Do	
8	156.75	66	14.5	.0925	10.810	Do	
9	158.75	75	14.75	.0929	10.762	Do	
10	159.75	75	15.	.0939	10.650	Clear red	
11	157.5	65	15.25	.0967	10.327	Do	
12	157.75	70	17.25	.1093	9.145	Bright red	

The mean amount of metal to the ounce of steam in the five experiments marked *comparable* in the above table, is $10\frac{96}{100}$ ounces, which may be assumed as 11 without sensible error.

SIXTH SERIES,

To determine the quantity of steam yielded by given weights of cast brass at red heat, when plunged into water at 212°.

No. of experiments.	Weight of brass in ounces.	Time, in seconds.	Ounces of steam produced.	Weight of steam to an ounce of metal.	Ounces of metal to one ounce of steam.	Heat Observed.	Remarks.
1	176	70	15.75	.0895	11.809	Red only in the dark	Immersed at once
2	176	120	16.5	.0943	10.666	*Comparable.* (dull red)	Do by degrees
3	175	60	16.75	.0958	10.448	Do	Do at once
4	176	105	17.	.0966	10.353	Do	Do more gradua[lly]
5	175	120	17.25	.0985	10.145	Do	Do slowly
6	175	120	17.25	.0985	10.145	Do	Do do
7	175	180	18.	.1028	9.722	Clear red	Do do
8	176	75	19.	.1085	9.263	Full red	Do at once
9	176	120	22.	.1250	8.000	Bright red	Do gradually

The five experiments which were made at a dull red heat in day light, nd which were therefore marked *comparable*, prove that, on an average, ne pound of steam requires $10\frac{35}{100}$ pounds of cast brass of that temperature or its production. It was observed that the violence of agitation, when rass was employed, appeared to be much greater than when similar masses f iron were the subjects of experiment. This was attributed to its higher onducting power. A repetition of this series might not exhibit precisely ne same results, unless the specimens employed should have the same proortion of ingredients, and the same specific gravity.

SEVENTH SERIES,

Vith ingots of standard silver, of various weights, from $21\frac{1}{2}$ to $195\frac{1}{2}$ ozs. avoirdupois.

ment.	Weight of silver, in ounces avoirdupois.	Time, in seconds.	Weight of steam produced.	Parts of steam to one ounce of metal.	Ounces of metal to one ounce of steam.	Heat observed.	Remarks.
1	195.5	120	10.	.0511	19.550	*Comparable,* (dull red.)	Immersed by degrees.
2	26.5	30	1.375	.0519	19.272	Do.	Do. at once.
3	26.5	33	1.5	.0566	17.666	Do.	Do. do.
4	26.5	30	1.75	.0660	15.143	Clear red.	Do. do.
5	26.5	32	1.75	.0660	15.143	Do.	Do. more gradually.
6	41.2	50	3.0625	.0740	13.453	Do.	Do. at once.
7	41.2	55	3.125	.0758	13.120	Full red.	Do. do.
8	195.5	130	15.	.0767	13.033	Do.	Do. gradually
9	21.5	30	1.75	.0814	12.286	Do.	Do. at once.
10	41.2	68	3.5	.0849	11.771	Do.	Do. gradually
	26.5	30	2.5	.0943	10.600	Bright red.	Do. at once, silver beginning to soften.

From a comparison of the three experiments marked *comparable*, in the ove table, it appears that about $18\frac{83}{100}$ pounds of standard silver will be quired for generating one pound of steam.

EIGHTH SERIES,

With an ingot of pure gold, weighing 14 lbs. 8¼ oz. avoirdupois,* and other circumstances as in preceding series, the following results were given:

No. of experiment.	Weight of gold in oz. avoirdupois.	Time, in seconds.	Weight of steam produced.	Weight of steam to unit of metal.	Ounces of metal to unit of steam.	Heat of metal.	Observations.
1	232.25	100	2 oz.	.0086	116.125	Red in the dark.	The water had remained exposed a short time, and probably lost a few degrees before this experiment.
2	232.25	120	5 "	.0215	46.450	Comparable.	Plunged by degrees.
3	232.25	125	6 "	.0258	38.708	Comparable.	Do.

The mean of the two experiments made at the temperature of comparison, is $42\frac{55}{100}$ pounds of metal to each pound of steam. The extremely low specific heat of gold, renders necessary every precaution formerly detailed in regard to avoiding loss of temperature in the water between two successive experiments, and also demands peculiar accuracy and despatch in the process of weighing. After all the efforts which were made to insure a correct result, it may have happened that a few degrees of heat in the gold were expended in *raising temperature*, and a corresponding deficiency in the quantity of heat *of elasticity* may have been the consequence.

The following summary exhibits a comparative view of the several metals submitted to trial, as shown in the preceding series, indicating the mean result of those experiments in each series which were made at the comparable temperature.

From all the preceding series, it appears that, at comparable temperature, each pound of steam requires for its production, of

Cast iron,	8¼	pounds,
Wrought iron,	9	do
Wrought copper,	$10\frac{35}{100}$	do
Cast brass,	$10\frac{96}{100}$	do
Standard silver,	$18\frac{83}{100}$	do
Pure gold,	$42\frac{58}{100}$	do.

If the temperature assumed for comparison be precisely as much above 212° as is equal to the number of degrees of heat which become latent in water while it passes into steam, it is evident that any substance at *comparable* temperature, and *possessing the same specific heat as water*, would generate its own weight of steam in cooling down to 212°. But if its own specific heat be less than that of water, its weight must be proportionally increas-

* The above mentioned mass of gold, at the Mint valuation of 4 1-25 cents per grain, was worth $4105.448. For the use of this, as well as of several ingots of silver, and for other conveniences in these experiments on the precious metals, I am indebted to the politeness of Dr. Moore, superintendent, Mr. Eckfeldt, chief coiner, and other officers of the United States' Mint.

ed, and then the effect of cooling will be the production of the same weight of steam as before supposed. Hence, as the *specific heat* is directly proportional to the quantity of *steam* which a given weight of metal would produce, the latter may, at a known temperature, be assumed as a measure of the former. By the following comparison it will be evident that the temperature adopted in these experiments *was* nearly identical with that which I have above alluded to, and which exceeds 212°, by the amount of latent heat (990°) in a unit, by weight, of steam.

	Steam to the unit of metal.	Specific heat.	
Iron,	.1111	.1100	Petit & Dulong.
Copper,	.0907	.0949	do.
Brass,	.0940	.1100	Dalton.
Silver,	.0532	.0557	Petit & Dulong.
Gold,	.0236	.0298	do.

It must be observed that the above statements of specific heats, taken from Petit and Dulong, are those of the mean effect from 0° to 100° centigrade. That of silver, for example, is .0557 within these limits, but if the mean specific heat found by them from 0° to 300° cent. be adopted, it will come somewhat above the result of my experiments, that is, .0611.

The method which has thus been adopted, adds another to the means heretofore employed for determining the specific heat of many solid and gaseous substances, or at least of verifying the results of former methods. The three modes just alluded to are those of *mixture*, of *melting ice*, and of *cooling in air:* the last, in particular, seems liable to many objections on account of the different conducting and radiating power of the bodies, and the different natures of the surface which may be given to each, whereby the *time* of cooling, which is made the measure, will be exceedingly variable.

The calorimeter, of Lavoisier, is not regarded as correct in its indications, on account of the subsequent congelation of a portion of the ice melted by the hot body; and the rise of temperature in water by *mixture,* involves the necessity of considering the increase of temperature in the containing vessel, together with its separate specific heat, before any accurate result can be anticipated. The method of generating steam from an apparatus kept at a uniform temperature, and by means of bodies of known *superior temperatures,* is, I conceive, less liable to objection from any of these sources of fallacy. The only modifying cause, which deserves much attention, is the *barometric pressure* during the experiment, which involves, also, a consideration of the specific heat of steam under different pressures; but as this source of error may be obviated by performing experiments at uniform pressures, we need hardly take it into view in estimating the general correctness of the mode now proposed of verifying the specific heats of bodies.

By knowing at what temperature we plunge a piece of metal under boiling water, the weight of the metal, and its mean capacity for heat, we may readily infer, from what is known of the quantity of latent heat in the unit by weight of steam, what weight of the liquid will be boiled off while the metal is reduced from a superior temperature down to 212°.

Thus let the *temperature* of the metal above 212° $= t$
Its *weight* $= w$
Its mean *capacity* between 212° and the known temperature $= c$
The latent *heat* of atmospheric steam $= l$

The weight of *steam* which the metal can produce $=s$

Then will $s=\frac{tcw}{l}$. Thus, suppose $t=2000°$, $c=.1111$, $w=16$ ounces, and $l=990°$, then we shall have $\frac{tcw}{l}=\frac{2000\times.1111\times16}{990}=3{,}571$ ounces.

From the above formula, we derive immediately an expression for the *temperature* when all the other elements are known; for $ls=tcw$, whence $t=\frac{ls}{cw}$; so that when we would determine the actual temperature of a body above 212°, whose specific caloric has been carefully ascertained, we have only to *find what weight of vapor it will produce in coming down to the point of ebullition; multiply this by the latent heat in steam, and divide the product by the product of the weight of heated matter multiplied by its specific heat.* Upon the basis of this proposition, I have constructed an instrument called the *steam pyrometer,* to be applied to the measurement of heat in incandescent metals, coals, and furnaces, to mark the melting point of metals, to verify the results presented by other instruments employed in similar operations, and to answer some other practical and scientific purposes.

The several series of experiments heretofore detailed, in relation to the actual *quantity* of vapor yielded by red hot metal, and to the *time* employed in producing it, have furnished some of the data for calculating the effect of overheating a steam boiler, and immediately furnishing it with water. It is evident, that, even with the same temperature in the metal, certain circumstances may exist at one time which shall modify the result exhibited at another. The tenth experiment in the fourth series, in which 60 ounces of metal continued red for 82 seconds, beneath the surface of boiling water, and afterwards occupied 46 seconds in parting with the excess of heat above 212° which then remained, might possibly lead to the inference, that the quantity of heat disengaged in the former part of the operation was at least twice as great as that which was given out in the latter. This would imply that the temperature, (omitting difference in specific heat,) had been at first three times as much above 212°, as it was at the moment when redness disappeared. But the whole of the fourth series, as well indeed as all the other series heretofore given, had manifested, in the performance of the experiments, a much more vigorous action subsequent to the disappearance of redness, than before that period. It was therefore necessary, in order to obtain some degree of clearness on this head, to perform several *courses,* each consisting of a number of *series* of experiments.

The general fact that red hot metal repels water, or at least does not appear to exercise upon it any *contiguous* attraction, has long been familiar. The smith who plunges a piece of iron, at a white heat, into his trough, sometimes sees with astonishment that scarcely any agitation of the liquid occurs for the first few seconds; and he perceives that this is not due to the coldness of the water, requiring it to be heated up to boiling temperature, before it can undergo the agitation consequent upon the formation of steam; for, by plunging another piece of metal at a black heat into the same liquid, the action becomes immediately and distinctly perceptible.

When water is sprinkled upon a stone plate, even below redness, the drops are often observed to roll, apparently with little or no adhesion, from side to side, until slowly dissipated, or until they at length become attached and finally disappear, amidst a rapid ebullition, and a violent hissing noise.

In the use of his generators, sometimes at the temperature of redness, Mr. Perkins had occasion to notice the fact above described, and to observe that the repulsion, between the metal and the water, sometimes becomes intense, amounting to a force greater than that of the elasticity of the steam, and that a small pipe heated red hot, might become entirely choked up, so to speak, with caloric, and incapable of transmitting any water or steam.

It may also be mentioned, that Klaproth has performed some experiments on a small scale, illustrative of one part of the subject now under consideration. But they seem to have given rise to some erroneous deductions in regard to the action of metal. It appears to have been inferred that, as in cooling his *spoon* down from a white to a black heat, he passed from the time of 40'' to 0'' in the evaporation of six drops, he had actually arrived at a point where the action of metal upon water would be *instantaneous*.

From his experiments, and those of Perkins, it has likewise been inferred that the point of *incandescence* is that from which the repulsion of water from the surface of metal commences; and that, above redness, the augmentation of temperature is always attended by a corresponding diminution in the rapidity of evaporation. An opportunity will perhaps be embraced in a future paper to recur to these opinions.

The mode of performing the first of the following courses of experiments, was by procuring a basin of wrought iron about eight inches broad, one inch and three-fourths deep at the centre, and one fourth of an inch thick, made from a piece of rolled iron, and weighing three pounds and a half. This was heated, either over a spirit lamp, with an argand burner, in a stove of anthracite, capable of maintaining a heat near whiteness, or at a forge fire, urged by a powerful bellows. When deemed sufficiently hot, it was withdrawn from the fire, and care being taken that no dust or ashes adhered to the surface, a measured portion of water was laid upon the center, the time from the moment it struck the metal 'till the last drop disappeared being carefully noted from an accurate time keeper, and recorded by an assistant. The temperature of the water was marked by a good thermometer, or was kept boiling by remaining constantly over the fire during a whole series. The trials were continued as long as the metal remained hot enough to produce vapor of atmospheric elasticity. The proceeding has rendered it highly probable, that the rate of cooling, after the period of most rapid action has been attained, varies considerably from that which precedes, and that, possibly, different stages of rapidity will be discovered, in different parts of the series, following the time of most rapid vaporization.

First course, *comprising twelve series.*

Exhibiting the times in which given quantities of water of known temperature may be successively converted into vapor, while the iron which produces it is cooled from redness to the point of ebullition.

No. of exp. in each series.	1st series, 1.7.8 oz. water at 194° Fahr.	2d do. 1-2 oz. do. 200° do. 8 experiments.	3d do. 1-4 oz. do. 178° do. 11 experiments.	4th do. 1-8 oz. do. 190° do. 13 experiments.	5th do. 1-8 oz do. 188° do. 14 experiments.	6th do. 1-8 oz. do. 185° do. 14 experiments.	7th do. 1-8 oz. do. 190° do. 15 experiments.	8th do. 1-8 oz. do. 178° do. 17 experiments.	9th do. 1-8 oz. do. 188° do. 17 experiments.	10th do. 1-8 oz. do. 182° do. 18 experiments.	11th do. 1-16 oz. do. 175° do. 25peeriment s.	12th do. 1-16 oz. do. 188° do 29 experiments.
	″	″	″	″	″	″	″	″	″	″	″	″
1	50	105	93	173	126	134	121	66	111	78	66	80
2	55	25	23	19	14	15	16	18	13	12.5	17	37
3	176	15	12	9	9	6.5	7.5	9	9	5.5	7.5	14.5
4	.	21	14	14	11.5	10	9	9	9	7.5	7	9
5	.	31	19	17	14.5	14.5	12	11	10	9	6	6.5
6	.	41	25	22	17	16	15	14	11.5	11	5.5	6
7	.	69	30	24	19.5	19.5	16.5	15	15	14	5.5	5.5
8	.	150	43	28	21.75	20	19	19	17	14.5	5	6.5
9	.	.	57	37	26	27	22	20	19	17	5	7
10	.	.	67	50	31	30	26.5	22	23	19	5.5	8
11	.	.	135	63.5	38	38	30	25	27	22	5.75	8
12	.	.	.	99	49	49	39.5	31	30	24	6	8.5
13	.	.	.	174	70	66	54	38	41.5	25	7	9.5
14	-	.	.	.	89	99	72	45	50.5	33	7.5	11
15	.	.	.	.	.	.	107	68	72	40	8	11.5
16	.	.	.	.	.	.	.	95	93	50	13	13
17	.	.	.	.	.	.	.	190	183	82	18	14
18	.	.	.	.	.	.	.	.	.	135	20	15
19	.	.	.	.	.	.	.	.	.	.	22	15.5
20	.	.	.	.	.	.	.	.	.	.	25	17
21	.	.	.	.	.	.	.	.	.	.	34	19
22	.	.	.	.	.	.	.	.	.	.	42	22
23	.	.	.	.	.	.	.	.	.	.	50	26
24	.	.	.	.	.	.	.	.	.	.	83	30
25	.	.	.	.	.	.	.	.	.	.	140	36
26	.	.	.	.	.	.	.	.	.	.	.	44
27	.	.	.	.	.	.	.	.	.	.	.	59
28	.	.	.	.	.	.	.	.	.	.	.	89
29	.	.	.	.	.	.	.	.	.	.	.	155.5

RESULTS.

1st series. $5\frac{5}{8}$ oz. generated in 281″
2 intervals, 60″ each 120

Whole time of the series, 401

2d series. 4 oz. generated in 457″
7 intervals 10″ each 70

Whole time of the series 527

3d series. $2\frac{3}{4}$ oz. generated in 518″
10 intervals, 6.5″ each 65

Whole time of the series 583

4th ser. $1\frac{5}{8}$ oz. generated in 727.5″
12 intervals, 6.8″ each 82.5

Whole time of the series 810

5th ser. $1\frac{3}{4}$ oz. generated in	536″	9th ser. $2\frac{1}{8}$ oz. generated in	724″
13 intervals, 12.9′ each	169	16 intervals, 11″ each	176
Whole time of the series	705	Whole time of the series	900
6th ser. $1\frac{3}{4}$ oz. generated in	534.5″	10th ser. $2\frac{1}{4}$ oz. generated in	598.5″
13 intervals, 10.8 each	140.5	17 intervals, 16″ each	271.5
Whole time of the series	675	Whole time of the series	870
7th ser. $1\frac{7}{8}$ oz. generated in	567″	11th ser. $1\frac{9}{16}$ oz. generated in	613″
14 intervals, 10″ each	140	24 intervals, 7″ each	168
Whole time of the series	707	Whole time of the series	781
8th series. $2\frac{1}{8}$ oz. generated in	695″	12th ser. $1\frac{13}{16}$ oz. gener'd in	780.5″
16 intervals, 6″ each	96	28 intervals, 8.2″ each	230.5
Whole time of the series	791	Whole time of the series	1011

As the water covered generally but a small part of the surface of the basin even at the commencement of the experiment, the heat in the latter terms of each series, must have been furnished to the water more slowly than in the preceding terms, both on account of the diminution of difference between the metal and the liquid, and on account of the necessity of depending on the conducting power of the metal to bring the heat from the exterior to the center of the basin. Hence we might expect to find the terms obeying some law of geometrical progression. If we examine the last seven or eight experiments in each series, we shall clearly perceive such a progression. Omitting the last of each column, as presenting anomalies obviously derived from the final disappearance of vaporization, and the substitution of mere *evaporation,* we may divide the last number but one by that which precedes it; this latter, by the next preceding, and so on, until we obtain five quotients. These quotients will constitute the ratios of the series at the particular points where the experiments took place. The mean results for each series may then be obtained in the usual mode. But it will soon be perceived that, if we extend the divisions beyond five or six, the ratio will be essentially varied in its character, and the series, in some instances, becomes almost exactly coincident with an arithmetical progression. Thus the 12th series, from the 11th to the 20th experiment, inclusive, may be regarded as composed of the numbers 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, while from the 23rd to the 28th, we have 26, 30, 36, 44, 59, 89, yielding the ratios $\frac{30}{26} = 1.153$, $\frac{36}{30} = 1.200$, $\frac{44}{36} = 1.222$, $\frac{59}{44} = 1.341$, and $\frac{89}{59} = 1.508$, and the mean of all these ratios is 1.285.

By similar operations applied to the concluding part of every series in this course, except the first and second, we obtain the following mean ratios for the several series respectively, viz.

For the	3d	series	1.290
"	4th	"	1.334
"	5th	"	1.276
"	6th	"	1.302
"	7th	"	1.270
"	8th	"	1.308
"	9th	"	1.285
"	10th	"	1.292
"	11th	"	1.316
"	12th	"	1.285

If we would know the mean of all their mean ratios, we have but to divide their sum by 10, the number of series considered, whence we obtain 1.296 for the general ratio of this part of the several series. It will, however, be remarked that the five ratios belonging to the 11th series are themselves in geometrical progression, whose mean ratio is 1.07.

In order to present to the eye the whole range of experiments in some of the series, I have adopted the method of curvilinear projection, assuming, as the unit of vapor, the amount actually employed at each trial, and, as the unit of time, the number of seconds taken to vaporize it at the period of most rapid action. Representing these units by equal vertical and horizontal lines respectively, the relative time of action in each experiment marked on the line *a c*, is denoted by the dotted lines, *a d*, *c g*, &c. Figs. 1, 2 and 3. Regarding *ab* as a constant quantity, we have the portions of time above the *minimum*, represented by that part of each vertical which is above the tangent *b f.* It will be seen by Fig. 1. that the arithmetical series exists in the 6th, 7th, and 8th experiments. Fig. 2d. shows the same feature at the 17th, 18th, and 19th, while the 12th series, represented by Fig. 3, shows a straight line from No. 11 to No. 20, as already stated.

The next course of experiments was performed on a more extended scale, by using a cylinder of cast iron about seven inches long, and three inches in diameter; having at one end a cylindrical hole nine-tenths of an inch in diameter, and three and three quarters of an inch in depth, concentric with the axis of the cylinder, and of course penetrating below the centre of the mass. The weight of the cylinder was about ten pounds. This cylinder, heated to redness, was placed on the solid base, and the water was deposited from a suitable measuring tube, in the hole at the upper end, due care being taken to clear the interior surface of scales and dust at the moment it was withdrawn from the fire. In this course, the red heat was maintained for a much longer period than was practicable with the rolled plate, when withdrawn from the fire. The time when redness disappeared, was generally noted, and is marked *b* against the number of seconds registered at the experiment where it occurred. The *minimum* time is indicated in like manner by *m*.

SECOND COURSE, *containing nine series.*

To exhibit the rate of decrease, the time of most violent action, and the subsequent increase of time of vaporization in a cylinder of cast iron, employing an equal quantity of water at each trial in the same series.

Order of succession in the experiments of each series.	1st series, 1-8 oz. of water, at 65° at each exp. Iron red hot when taken from the fire.	2d series, 1-8 oz. of water, at 80°. Iron very bright red.	3d series, 1-4 oz. of water, at 212°. Iron near whiteness.	4th series, 1-8 oz. of water, at 190°. Iron bright red.	5th series, 1-8 oz. of water, at 190°. Iron bright red.	6th series, 1-8 oz. of water, at 200°. Iron near whiteness.	7th series, 1-8 oz. of water, at 200°. Iron nearly white.	8th series, 1-16 oz. of water, at 212°, kept in rapid ebullition during the whole series. Iron white.	9th series, 1-16 oz. of water, at 212°, kept briskly boiling. Iron white.
	"	"	"	"	"	"	"	"	"
1	31	26.5	27	14	14.5	18	20	27.5	17
2	30	26	27	13	14	16	20	28	17
3	30	26	24	12	14	16	19	34	15
4	30	26	23	11.5	14	16	18	39	15
5	31	26	23	10.5	14	15.5	17.5	30	14.5
6	34	25	20	10.5	13	15	17	33	14.5
7	30	24	20	10.5	12	14.5	17	22	14.5
8	33	24	19	10	11	14	17	20	13
9	34	22	17	10	11	13	17	18	13
10	29	21	15	10	12	12	16	17	12
11	27.5	19	13	10	11	12	15	17	11.5
12	27.5	18.5	13	9.5	11	11	14.5	16	11.5
13	30	18	12	9.5	11	11	14	16	11
14	31	18.5	12	9	11	11	14	16	12
15	29	18	12	9	10	11	13	16	12
16	29	18.5	12	9	10	11	13	16	12
17	25	18	11	8.5	10	10.5	12	15	12
18	21	18	10	8	10	10.5	12	15	12
19	20*b*.	17.5	10*b*	8	10	10	12	15	11
20	20	17.5	10	8	10	10	11	14.5	11
21	20	17*b*	10	8.5	10	10	10	14.5	11
22	20	17	10	8	9.5	10	10	13	10
23	19	17	10	8	9.5	10	9.5	12	10
24	19	17	10	7.5	9.5	10	9.5	12	10.5
25	21	17	8.5	7	10	10	9.5	11	10
26	21	16.5	8.5	7	9.5	10	9.5	10.5	9
27	22	16.5	8	7	9.5	9.5	9	10	8.5
28	20	17	8	7	8	9.5	9	10	9
29	23	16.5	8	6.5*m*	8	9	8.5*b*	10	9
30	17	16.5	8	7*b*	8	9*b*	8	9	8.5
31	20	16	7	8	7*b*	9	7.5	9	8.5
32	18	16	7	8	6*m*	8.5	7	9	8.5

TABLE—Continued.

Order of succession in the experiments of each series.	1st series, 1-8 oz. of water, at 65° at each exp. Iron red hot when taken from the fire.	2d series, 1-8 oz. of water, at 80°. Iron very bright red.	3d series, 1-4 oz. of water, at 212°. Iron near whiteness.	4th series, 1-8 oz. of water, at 190°. Iron bright red.	5th series, 1-8 oz. of water, at 190°. Iron bright red.	6th series, 1-8 oz. of water, at 200°. Iron near whiteness.	7th series, 1-8 oz. of water, at 200°. Iron nearly white.	8th series, 1-16 oz. of water, at 212°, kept in rapid ebullition during the whole series. Iron white.	9th series, 1-16 oz. of water, at 212°, kept briskly boiling. Iron white.
	"	"	"	"	"	"	"	"	"
33	18	16	7	8	6	8	7	8.5	8
34	17	16.5	7	7.5	8	8	6.5	8.5	8
35	17	16.5	7	7.5	7	8	7	8	8
36	16.5	16	6.5	8	7	8	8	8	8
37	16	16	7	7.5	7	8	7	7	8
38	15	15	6.5	7	7	8.5	7	7*b*	8
39	15	14	7	8	7	8.5	7	7	7
40	15	14	6.5	7.5	8	7	6.5	7	7
41	14.5	14	7	7.5	8	7	6.5	7	7
42	18	14	6*m*	7.5	7	7	6	7	6.5*b*
43	16.5	14	7	7.5	7	7	6	6.5	7
44	15	14	7	8	7	7	6	6.5	7
45	16	14	7	7.5	8	7	6	6	7
46	15	14.5	6.5	7.5	8	6.5	6.5	6	6.5
47	15	14.5	7	8	8	6*m*	6.5	6	6.5
48	15	14	6.5	8	9	6.5	6.5	6	6.5
49	13*m*.	14	7	8.5	9	7	6	6	6.5
50	13	13*m*	7	9	9	7	6	5.5	6.5
51	13	13	6.5	9	9	7	6	5.5	6.6
52	13	14	6.5	9.5	9	7	5*m*	5*m*	6
53	13	14	7	10	9.5	7	6	5	6
54	16	14	8	11	9.5	7	6	6	6
55	21	15	8	12	10	7	6	5	6
56	22	15	9	12.5	11	7	6	6	5
57	23	18	10	12.5	10.5	8	7	5	6
58	26.5	19	10	14	12	8	6	5	5.5
59	47	22.5	12	14	11	8	6	5	5.5
60	210	25	15	14	12	8	6.5	5	5
61	-	43	19	15	13	8	6.5	5	6
62		188	24	16.5	14	8	7	5	6
63		-	27	18	14	8	7	5	6
64		-	36	19	14	7.5	7	5	5
65		-	40	21	15	7.5	7	6	5.5
66		-	55	23.5	16	8	7	5.5	5
67			80	28	17	8	7	6	5
68			137	31.5	20	9	8	6	6
69		-	-	33	20	10	8	6	5.5

TABLE—Continued.

Order of succession in the experiments of each series.	1st series, 1-8 oz. of water, at 65° at each exp. Iron red hot when taken from the fire.	2d series, 1-8 oz. of water, at 80°. Iron very bright red.	3d series, 1-4 oz. of water, at 212°. Iron near whiteness.	4th series, 1-8 oz. of water, at 190°. Iron bright red.	5th series, 1-8 oz. of water, at 190°. Iron bright red.	6th series, 1-8 oz. of water, at 200°. Iron near whiteness.	7th series, 1-8 oz. of water, at 200°. Iron nearly white.	8th series, 1-16 oz. of water, at 212°, kept in rapid ebullition during the whole series. Iron white.	9th series, 1-16 oz. of water, at 212°, kept briskly boiling. Iron white.
				"	"	"	"	"	"
70	-	-	-	39	22	10	8	6	5
71	-	-	-	56	22	10	9	6	5
72	-	-	-	64	23	10	9.5	6	5
73	-	-	-	179	24	10	10	6	5
74	-	-	-	-	25	10.5	10	6.5	5
75	-	-	-	-	28	10.5	10	6.5	4.5m
76	-	-	-	-	37	11	10	6	5
77	-	-	-	-	46	12	10	6	4.5
78	-	-	-	-	54	13	10	6	6
79	-	-	-	-	88	13	10.5	6	5
80	-	-	-	-	154	14	10.5	5.5	5
81	-	-	-	-	-	15	11	5.5	5.5
82	-	-	-	-	-	15	13	5.5	5
83	-	-	-	-	-	18	14	5.5	5
84	-	-	-	-	-	19	14.5	5.5	5
85	-	-	-	-	-	20.5	17.5	6	5
86	-	-	-	-	-	24	18	5.5	5
87	-	-	-	-	-	25.5	19	6	5
88	-	-	-	-	-	33	21	6	5
89	-	-	-	-	-	44	23	6	4.5
90	-	-	-	-	-	56	26	6.5	5
91	-	-	-	-	-	92	29	6	5
92	-	-	-	-	-	296	38	6	4.5
93	-	-	-	-	-	-	60	6	4.5
94	-	-	-	-	-	-	163	6	4.5
95	-	-	-	-	-	-	-	6	5
96	-	-	-	-	-	-	-	6	6
97	-	-	-	-	-	-	-	6.5	5
98	-	-	-	-	-	-	-	6.5	5.5
99	-	-	-	-	-	-	-	6.5	5
100	-	-	-	-	-	-	-	6.5	6
101	-	-	-	-	-	-	-	6.5	5
102	-	-	-	-	-	-	-	7	5.5
103	-	-	-	-	-	-	-	7	5
104	-	-	-	-	-	-	-	7	5.5
105	-	-	-	-	-	-	-	7	6
106	-	-	-	-	-	-	-	7	5.5

TABLE—Continued.

Order of succession in the experiments of each series.	1st series, 1-8 oz. of water, at 65° at each exp. Iron red hot when taken from the fire.	2d series, 1-8 oz. of water, at 80°. Iron very bright red.	3d series, 1-4 oz. of water, at 212°. Iron near whiteness.	4th series, 1-8 oz. of water, at 190°. Iron bright red.	5th series, 1-8 oz. of water, at 190°. Iron bright red.	6th series, 1-8 oz. of water, at 200°. Iron near whiteness.	7th series, 1-8 oz. of water, at 200°. Iron nearly white.	8th series, 1-16 oz. of water, at 212°, kept in rapid ebullition during the whole series. Iron white.	9th series, 1-16 oz. of water, at 212°, kept briskly boiling. Iron white.
								"	"
107	-	-	-	-	-	-	-	7	6
108	-	-	-	-	-	-	-	7	6
109	-	-	-	-	-	-	-	7	5.5
110	-	-	-	-	-	-	-	7	6
111	-	-	-	-	-	-	-	7	5.5
112	-	-	-	-	-	-	-	7	6
113	-	-	-	-	-	-	-	7	5.5
114	-	-	-	-	-	-	-	7	5.5
115	-	-	-	-	-	-	-	7	5.5
116	-	-	-	-	-	-	-	7	5
117	-	-	-	-	-	-	-	7	6
118	-	-	-	-	-	-	-	6.5	5.5
119	-	-	-	-	-	-	-	6.5	5.5
120	-	-	-	-	-	-	-	7	5.5
121	-	-	-	-	-	-	-	6	6
122	-	-	-	-	-	-	-	6	6
123	-	-	-	-	-	-	-	6.5	7
124	-	-	-	-	-	-	-	6	6
125	-	-	-	-	-	-	-	6	6.5
126	-	-	-	-	-	-	-	6.5	6.5
127	-	-	-	-	-	-	-	7	6.5
128	-	-	-	-	-	-	-	6.5	7
129	-	-	-	-	-	-	-	7	7
130	-	-	-	-	-	-	-	6	7
131	-	-	-	-	-	-	-	6	6.5
132	-	-	-	-	-	-	-	6	6.5
133	-	-	-	-	-	-	-	7	5
134	-	-	-	-	-	-	-	7	6
135	-	-	-	-	-	-	-	7	6
136	-	-	-	-	-	-	-	7	5.5
137	-	-	-	-	-	-	-	7	6
138	-	-	-	-	-	-	-	7.5	6
139	-	-	-	-	-	-	-	7.5	6
140	-	-	-	-	-	-	-	7.5	6
141	-	-	-	-	-	-	-	7.5	5
142	-	-	-	-	-	-	-	8	5.5

TABLE—Continued.

Order of succession in the experiments of each series.	1st series, 1-8 oz. of water, at 65° at each exp. Iron red hot when taken from the fire.	2d series, 1-8 oz. of water, at 80°. Iron very bright red.	3d series, 1-4 oz. of water, at 212°. Iron near whiteness.	4th series, 1-8 oz. of water, at 190°. Iron bright red.	5th series, 1-8 oz. of water, at 190°. Iron bright red.	6th series, 1-8 oz. of water, at 200°. Iron near whiteness.	7th series, 1-8 oz. of water, at 200°. Iron nearly white.	8th series, 1-16 oz. of water, at 212°, kept in rapid ebullition during the whole series. Iron white.	9th series, 1-16 oz. of water, at 212°, kept briskly boiling. Iron white.
								"	"
143	-	-	-	-	-	-	-	8.5	5.5
144	-	-	-	-	-	-	-	9	5
145	-	-	-	-	-	-	-	9	5
146	-	-	-	-	-	-	-	10	5
147	-	-	-	-	-	-	-	10.5	5
148	-	-	-	-	-	-	-	12	5
149	-	-	-	-	-	-	-	12	6
150	-	-	-	-	-	-	-	12	5.5
151	-	-	-	-	-	-	-	13.5	5
152	-	-	-	-	-	-	-	15	5
153	-	-	-	-	-	-	-	15.5	6
154	-	-	-	-	-	-	-	18	6
155	-	-	-	-	-	-	-	20	6
156	-	-	-	-	-	-	-	22	6
157	-	-	-	-	-	-	-	29	6
158	-	-	-	-	-	-	-	32	7
159	-	-	-	-	-	-	-	33	6
160	-	-	-	-	-	-	-	37	7
161	-	-	-	-	-	-	-	58	6.5
162	-	-	-	-	-	-	-	88	7.5
163	-	-	-	-	-	-	-	154	8
164	-	-	-	-	-	-	-	-	10
165	-	-	-	-	-	-	-	-	11
166	-	-	-	-	-	-	-	-	14
167	-	-	-	-	-	-	-	-	15.5
168	-	-	-	-	-	-	-	-	20
169	-	-	-	-	-	-	-	-	25
170	-	-	-	-	-	-	-	-	32
171	-	-	-	-	-	-	-	-	47
172	-	-	-	-	-	-	-	-	69
173	-	-	-	-	-	-	-	-	134

RESULTS.

1st series:—Vaporized $\frac{60}{8}$ oz. of water in 2100″; viz.

Water was on the metal	1497″
59 intervals 10.2″ each	603″

Black at No. 19; minimum No. 49.

2d series:—Gave $\frac{62}{8}$ oz. of vapor in 1800″; viz.

Water remained on	1292.5″
61 intervals 8.32″ each	507.5″

Black at No. 21; minimum No. 50.

3d series:—Gave $\frac{68}{4}$ oz. of vapor in 1800″; viz.

Water was on	1065.5″
67 intervals 10.9″ each	734.5″

Black at No. 19; minimum No. 42.

4th series:—Gave $\frac{78}{8}$ oz. of vapor in 1920″; viz.

Water was on	1092″
72 intervals 11.5″ each	828″

Black at No. 30; minimum No. 29; (surface oxydized.)

5th series:—Gave $\frac{80}{8}$ oz. of vapor in 2100″; viz.

Water was on	1244.5″
79 intervals 10.8″ each	855.5″

Black at No. 31; minimum No. 32; (oxyde.)

6th series:—Gave $\frac{92}{8}$ oz. of vapor in 2100″; viz.

Water was on	1420″
91 intervals 7.47″ each	680″

Black at No. 30; minimum No. 47.

7th series:—$\frac{94}{8}$ oz. of vapor in 2162″; viz.

Water was on	1232″
93 intervals 10″ each	930″

Black at No. 29; minimum No. 52.

8th series:—Gave $\frac{163}{16}$ oz. of vapor in 2700″; viz.

Water was on	1819″
162 intervals 5.44″ each	881″

Black at No. 38; minimum No. 52.

9th series:—Gave $\frac{173}{16}$ oz. of vapor in 2700″; viz.

Water was on	1510″
172 intervals 6.91″ each	1190″

Black at No. 42; minimum No. 75.

The eighth series in the second course, is represented in projection by the curve (Fig. 4) of the accompanying plate. The reader will remark that the linear unit, assumed to represent the minimum time and its corresponding quantity of vapor, is one-tenth of an inch in this figure, whereas it is two-tenths in those which relate to the first course.

In addition to the results of the fourth and fifth series, where the most rapid action occurred almost simultaneously with the cessation of redness, numerous other facts had convinced me that the approach to this period is greatly accelerated by the adhesion of any non-conducting substance to the surface of the iron. Indeed, it often appeared sufficient for the water to find and seize upon a mere point of such material as a nucleus, to enable the

fluid speedily to reduce the temperature of the surrounding surface. By detaching a scale of oxyde, around which the effect just described had begun to take place, I have sometimes succeeded in arresting the progress of vaporization, and by giving the liquid once more a clean red surface, even with the scale floating loosely in the water, to establish once more the slow evaporation which belongs to that state of the metal.

To ascertain what effect the incrustation generally formed upon the interior of a steam boiler might be expected to produce, in augmenting the rapidity of action in a case of over-heating, I performed the following course of nine series, employing, for that purpose, the basin used in the first course, commencing with its surface clean, and having tried the effect of pure water at 212°, subsequently poured in a portion of cold water, into a pint of which about two ounces of clayey garden earth had been put, producing a degree of turbidness as great probably as any of our rivers possess in the time of freshets. The iron was kept constantly over a brisk fire, and, in some of the series, was permitted to come to bright redness before each experiment; while, in others, the operation commenced with redness, but was continued in so immediate a succession as to reduce the metal to a certain point of constant action, but never attaining the *most rapid* period.

It will be perceived that the first series was made in pairs, alternately, two with clean water at the boiling point, and two with the muddy water abovementioned. The other series were made with similar alternations of single experiments, with the exception that both hot and cold water were free from impurities when laid upon the metal. The ratios placed among the results of this course, will prove that, on an average, water at 212° laid upon hot metal under the circumstances described, requires 15½ per cent. longer for its evaporation than a like quantity of water at 60°. This result, which appears at first rather startling and paradoxical, is readily explained when we consider the efficacy of cold water in bringing the coating and even the surface of the metal down towards the temperature of most rapid action—a point at which the mere difference of temperature becomes an insignificant element in the calculation, compared with the vastly augmented speed with which the vapor is then generated.

THIRD COURSE, *embracing nine series.*

To exhibit the effect of incrustations in augmenting the action of hot metal, during the first stages of vaporization from its surface, and also to show the relative efficacy of hot and cold water in this particular.

Order of experiments in each series.	SERIES. 1st. Iron red; evaporated $\frac{1}{8}$ oz. of water at each experiment, gradually coating the surface with clay. Water, 212° clean.	Water 60° muddy.	2d. Commenced with iron red; $\frac{1}{8}$ oz. alternately clear and muddy water. Water 212° clean.	Water 60° muddy.	3d. Begun by evaporating 2 oz. of muddy water, forming a crust on the metal, on which put $\frac{1}{8}$ oz. each time. Water 212° clean.	Water 60° clean.	4th. $\frac{1}{8}$ oz. laid on crust of clay, in immediate succession. Water 212° clean.	Water 60° clean.	5th. $\frac{1}{4}$ oz. of water used each time, begun at bright red and brought down to a temperature of constant action. Water 212° clean.	Water 60° clean.	6th. $\frac{1}{4}$ oz.; iron red hot before each experiment. Water 212° clean.	Water 60° clean.	7th. Begun by adding $\frac{1}{3}$ oz. muddy water to the crust already formed. This evaporated in 45″. $\frac{1}{4}$ oz. each time; iron full red at every trial. Water 212° clean.	Water 60° clean.	8th. Added $\frac{1}{4}$ oz. of muddy water; took 35″; then iron red each time; hot and cold water applied; $\frac{1}{4}$ oz. at each experiment. Water 212° clean.	Water 60° clean.	9th. On the coat of clay from 4 oz. muddy water, put 1 oz. of clean water at 60°, in immediate succession.
	″	″	″	″	″	″	″	″	″	″	″	″	″	″	″	″	″
1	95	-	23	-	14	-	13.5	-	21	-	30.5	-	21.5	-	15	-	30
2	100	-	-	21.5	-	12	-	10.5	-	18	-	26	-	19	-	14.5	26
3	-	72	20	-	14	-	13	-	18	-	28	-	24	-	18	-	25
4	-	52	-	20	-	13.5	-	11	-	15	-	26	-	21	-	15.5	24
5	53	-	20	-	15	-	12	-	14.5	-	30.5	-	24.5	-	-	-	25
6	50	-	-	20	-	13	-	10.5	-	14	-	25	-	20	-	-	24.5
7	-	45	19	-	15.5	-	12	-	13.5	-	35	-	22.5	-	-	-	25
8	-	31	-	18	-	13.75	-	10.5	-	12	-	25	-	20	-	-	25
9	26	-	17	-	17.5	-	-	-	13	-	39	-	24				
10	24	-	-	17	-	14	-	-	-	13	-	29	-	21.5			
11	-	26	16.5	-	17.5	-	-	-	13	-	-	-	24				
12	-	27	-	16	-	14	-	-	-	11.5	-	-	-	21.5			
13	19	-	15.5	-	-	-	-	-	13	-	-	-	24.5				
14	23	-	-	15	-	-	-	-	-	11.5	-	-	-	21			
15	-	22	13.5														
16	-	21	-	14.5													
17	19	-	13.5														
18	18	-	-	13.5													
19	-	-	13.5														
20	-	-	-	13.5													
21																	

RESULTS.

1st series:—Time reduced from 100" to 18" by the coat of earthy matter successively deposited from $\frac{8}{8}$ths oz. of muddy water.

2d series:—Hot water constant at 13.5".
Cold water do do.

3d series:—Mean time for hot water 15.6"; coated metal red hot each time.
Mean time for cold water 13.37".
Ratio of cold to hot 1 : 1.167".

4th series:—Hot water constant at 12".
Cold water constant at 10.5".
Ratio of cold to hot 1 : 1.143.

5th series:—Hot water constant at 13".
Cold water constant at 11.5".
Ratio of cold to hot 1 : 1.130.

6th series:—Mean time for hot water 32.6".
Mean for cold water 26.2".
Ratio of cold to hot 1 : 1.244.

7th series:—Mean for hot water 23.6".
Mean for cold water 20.6".
Ratio of cold to hot 1 : 1.145.

8th series:—Mean for hot water 16.5".
Mean for cold water 15".
Ratio of cold to hot 1 : 1.100.

9th series:—Constant at 25" to the ounce.

The first series represents the gradual diminution of time from 100 "down to 18," and shows that here the impurity suspended in the water retarded vaporization more than the depression of temperature could accelerate it. In the second series the two effects became exactly counter-balanced, and so remained through several experiments more than are given in the table.

FOURTH COURSE, *consisting of six series.*

The sixth being intended to show the times required to evaporate or to vaporize equal portions of water from the surface of iron when placed cold upon a vivid coal fire, with the delays necessary to raise the temperature up to the point of most rapid action, and thence to the state in which the water ceases to moisten the surface; the other series being designed to exhibit the relation in time between hot and cold water upon a clean surface, varying the correspondent portions of each from $\frac{1}{8}$ oz. to 2 oz. at each experiment.

Order of experiments.	1st series. $\frac{1}{8}$ oz. at each experiment; hot and cold water alternately.		2d series. $\frac{1}{4}$ oz. at each experiment; hot and cold water alternately.		3d series. $\frac{1}{2}$ oz. at each experiment; hot and cold water alternately.		4th series. 1 oz. at each experiment; hot and cold water alternately.		5th series. 2 oz. at each experiment; hot and cold water alternately.		6th series. $\frac{1}{8}$ oz. put on the iron cold, and same quantity in immediate succession.
	Water 212°.	Water 60°.	Water 212°.	Water 60°.	Water 212°.	Water 60°.	Water 212°.	Water 60°.	Water 212°.	Water 60°.	Water 60°.
	″	″	″	″	″	″	″	″	″	″	″
1	104	-	108	-	150	-	182	-	266	-	40
2	-	68	-	93	-	137	-	158	-	220	15
3	96	-	102	-	150	-	-	-	-	-	9
4	-	64	-	84	-	126	-	-	-	-	Ceased 60″ 9
5	100	-	-	-	-	-	-	-	-	-	8
6	-	94	-	-	-	-	-	-	-	-	Ceased 30″ 8
7	90	-	-	-	-	-	-	-	-	-	6.5
8	-	79	-	-	-	-	-	-	-	-	6
9	95	-	-	-	-	-	-	-	-	-	Ceased 60″ 6
10	-	74	-	-	-	-	-	-	-	-	Black 64
11	90	-	-	-	-	-	-	-	-	-	Visibly red 60
12	-	80	-	-	-	-	-	-	-	-	75
13	80	-	-	-	-	-	-	-	-	-	Clear red 73
14	-	74	-	-	-	-	-	-	-	-	Do 80
Mean	93.5	76	105	88.5	150	131.5	182	158	226	220	Constant 80″
Ratio	1.23 : 1		1.186 : 1		1.14 : 1		1.151 : 1		1.209 : 1		

The mean of all these ratios is 1.183, which shows that, with a clean surface, the limited quantity of hot water requires $18\frac{3}{10}$ per cent. longer to effect its vaporization from the red hot metal, than an equal quantity of water at 60°; so that though the times are vastly different in this course from what were given in the last, the relation is nearly the same, being only three per cent. more favorable to the cold water than when the surface was incrusted with earthy matter. Accidental circumstances sometimes vary or even invert the relative times for hot and cold water, but such discrepancies are easily referred to their proper causes. The limits of this paper compel the postponement of several courses of experiments.

EXPERIMENTAL INQUIRIES, &c.

The development of the law of action between a heated surface and water of different temperatures, has been, in part, presented by preceding courses of experiments.

To persons conversant with this subject, it will readily occur that the facts and principles connected with vaporization are highly important to the arts, independently of their relation to the steam engine. The numerous processes of manufactures, in which liquids are to be reduced by boiling, are often performed in a manner totally at variance with philosophy as well as with economy. The manufacture of salt by vaporization, for example, is an extensive and increasing branch of our national industry, and is generally carried on with very little attention to the saving of fuel, by any of those devices and arrangements which the practical science of the present age might suggest.

The chief points proposed to be examined at present, are—

1. The *temperature of most rapid vaporization* under atmospheric pressure.

2. The nature of the phenemona exhibited at that point, as well as immediately above and below it.

3. Effects of lubricating the surface of the metal, of covering the surface of the water with a thin fibrous texture, and of thickening it with a farinaceous substance.

4. The influence of mechanical pressure in bringing the liquid in contact with the metal, and accelerating the vaporization.

5. The action of hot metal on other liquids, particularly alcohol.

6. Some opinions which have gained currency in regard to the temperature of repulsion, and the degree of rapidity with which heat may be imparted to liquids, will likewise require attention.

1. To ascertain the temperature at which the most rapid action takes place, two methods have been employed. The *first* was by using a basin of wrought iron, having at the bottom a small quantity of mercury, into which the bulb of a thermometer was plunged. Upon the surface of the iron, near the mercury, small measured portions of water were successively deposited, while the basin was placed over an argand spirit lamp. These portions were not of sufficient amount or frequency to prevent the increase of temperature in the metal, and consequently the times of vaporization were diminished to a certain point, after which they were observed to increase. The temperature had then reached the point were repulsion begins. The temperature, at the moment when the point of repulsion appeared to have been attained, was noted, and the experiments continued until an unequivocal increase in the time of evaporating the unit of water was observed. The lamp being now withdrawn, the temperature was allowed to descend, and the rapidity of vaporization was of course augmented; still lowering the temperature, the point of greatest action was passed, and the production of steam became slower from want of sufficient heat.

By thus reversing the temperatures, and alternately passing and repassing the point of most vigorous action, the limits of that action were determined to a certain degree of exactness. It soon became evident that it was far below the boiling point of mercury, and considerably above that of water boiling in open air. It was not difficult to ascertain, too, that the range of most rapid action lay between 300° and 350°. In order to vary

the mode of experimenting, and, at the same time, to give more exact indications in several particulars, the *second* method, above referred to, was devised. This consisted in employing a bar of iron about 14 inches long, $1\frac{7}{10}$ wide, and $1\frac{1}{10}$ thick. A number of cylindrical holes, half an inch in diameter, and one inch apart, (from center to center,) were bored along one of the sides, extending nearly through the thickness of the bar. Adjacent to each of these holes, which were five in number, were sunk small conical cavities, $\frac{3}{10}$ of an inch deep, and $\frac{7}{10}$ of an inch in diameter at top, forming basins or *cups* to receive drops or other small measured portions of liquids. The cylindrical holes were to receive mercury, into which the bulbs of thermometers could be plunged, to ascertain the temperature of the part of the bar, and of the cup opposite. The thermometers were supported from above, by hooks bent over the bar, and placed in proper positions to allow the bulbs to descend just far enough to be completely immersed in the reservoir of mercury, but not to carry the centre of the bulb below the level of the bottom of the contiguous cup.

By this means the temperature of the mercury was measured at a point where it must have been the same as that of the generating surface. The five receptacles of mercury were placed near the middle part of the bar, leaving a part four and a half or five inches long at each end, without holes; but the line of cups already mentioned was extended, in both directions, nearly to the extremities of the bar. By this means, the nature and mode of action could be observed at points above that of mercurial ebullition.

Heat was applied at one end of the bar, either by means of a spirit lamp, or by thrusting the end into an opening through the side of a furnace. As the temperature rose, the cups near the end next the fire, were, of course, first brought to a vaporizing temperature; then the cup opposite to the nearest mercurial reservoir, and the others in succession, with greater or less rapidity according to the tension of the heat at its source. It was generally found most advantageous to employ, for a source of heat, the convenient chemical spirit lamp, with argand burner, which has been devised by Dr. J. K. Mitchell. When the temperature was sufficiently raised, drops of water were simultaneously projected into two or more of the cups, and, by the inequality in the times of final disappearance, their relative influence was easily perceptible. This mode of operating, by allowing the temperature to be gradually raised, admitted of a succession of five series of trials, one for each cup, so that when the time of vaporization in one had begun to *increase*, that is, when the time of most rapid action in that cup had been passed, and the action had become slow through excess of heat, it was only necessary to commence with the next cup, more remote from the source of heat. The period of greatest rapidity was now perceived to lie between 304° and 320°. The range of temperature through which the most rapid action existed, was hence limited between two points, equally remote from 312°, or from 100° above the boiling point of water.

2. The nature of the effect here observed, resembled that of vigorous attraction. This necessarily creates a constant struggle between the vapor which is quitting, and the liquid which is approaching any given point of the metallic surface. On brass the action appeared more vigorous, and the temperature of repulsion higher than in the case of iron. On mercury at 500°, a drop of water was, on one occasion, found to remain seventy seconds; but, at 340°, a drop of this metal formed a good nucleus about which the water, when repelled by a surface of iron at the same temperature, would gather,

and thence obtain heat to vaporize itself, while portions not in contact with the mercury, would lie upon the iron almost quiescent.

At temperatures considerably below that of most rapid vaporization, there was constantly exhibited, in the various series of experiments, a decided tendency in the water to adhere to the metallic surface, and when by contact with a given portion of surface, and by receiving and rendering latent in vapor the heat which the latter had possessed, the temperature of that portion was somewhat reduced, the stratum of water was observed to glide away to other hotter parts of the service, even against the force of gravity.

This effect was observable in the cylinders with which the *second course* on *variable rapidity*, was performed. Towards the conclusion of each series, the water, after ceasing to boil in the bottom of the cylindrical cavity, ascended, in many instances, quite to the top of the cylinder, and even spread outward on all sides wherever it met with a higher temperature than 212°.

The same phenomenon was noticed in the basin already described, and in the bar above mentioned. To make this effect the more distinct, a broad shallow pan of extremely thin iron, commonly called, by the tin-plate workers, "block tin," was procured. In the centre of this, a slight elevation, about one-tenth of an inch high, was made, with a corresponding cavity on the under side, or bottom of the pan.

A lamp being applied beneath the elevated part, the iron soon obtained a dull red heat in the dark. Water was then laid upon the basin so as to surround completely the centre, and form a sort of island of heated surface. As the heat extended by degrees, and reached the line of water, the latter was observed to start upwards from its line, and moisten a portion of the surface not before wetted.

By agitating the water with a hair pencil, and creating a wave towards the centre, the *linae of vaporization* became distinct. By raising the waves still higher, that of repulsion was manifest, and, by causing a surge high enough to break quite over the insulated elevation, the alternate attractions and repulsions were seen in the drops and masses, which, having been driven forcibly beyond the first line of vaporization, or that which they encountered on their ascent, were subsequently rolled quite over the centre of the elevated embossment, but arrested, with great promptitude, as as they rolled down and reached the line of vaporization on the opposite side.

3. In order to ascertain the influence of certain lubrications in reducing the rapidity, I placed the bar over a spirit lamp in such a manner as to bring two of the mercurial reservoirs, and their adjacent cups, at equal distances from the centre of flame. Having allowed the temperature to reach 300°, I applied equal portions of water to each cup, and found their actions precisely alike. I then placed and spread, as lightly as possible, a minute portion of olive oil, forming a thin film over the surface of one of the cups, allowing the other to remain clean. On renewing the applications of water, it was found that the oiled took four times as long as the clean surface to vaporize a certain quantity of water. On elevating the temperature, the oil itself was gradually evaporated, and the water found occasional admittance to the surface. Hence the difference was gradually diminished, and the wonted action of the iron restored; but the addition of fresh portions of oil again reduced temporarily the vaporization on the surface to which it

was applied. But, as the temperature was more elevated than before, the oil likewise became sooner dissipated.

By exposing the bar in a similar manner, and ascertaining that two contiguous cups, equally remote from the centre of flame, were, when both clean, precisely alike in regard to the rapidity of evaporation at a high temperature, I lubricated one with plumbago, laid on by rubbing a piece of that substance over the interior, without however leaving any dust or small bits of the mineral to serve as *nuclei* for the water to seize upon. The other cup was left clean as before. Equal portions of water, at 60°, were now laid simultaneously upon the bottom of the two cups. The mean result of six experiments in each, was, that the cup with plumbago required eighty-four seconds to evaporate its liquid, while the cup without plumbago took but forty-one for that purpose. The portions of liquid used, were single drops for the respective experiments.

To ascertain the effect of thickening the water into a thin paste, I put a large teaspoonful of flour into an ounce of water, and laid one-fourth of an ounce of the mixture on the bottom of the iron basin, kept red hot over the fire. The evaporation took place, and the paste became dry in seventy-eight seconds. Under precisely the same circumstances, clear water, of the same temperature as that mixed with the flour, required one hundred and thirty-eight seconds to evaporate one fourth of an ounce.

The action on clear water was rendered much more rapid, however, by covering the surface with a circle of white paper laid on immediately after the water was put into the basin. The evaporation then took place in seventy-two seconds. In another experiment, in which the circle of paper was smaller than that of water, the time was increased to ninety seconds. In both of these cases, the acceleration appeared to proceed, in part, from the obstruction which the paper opposed to the rotation of the circle of water. When a very small circle of paper, or any other light body, was placed upon the surface, it soon acquired the motion of the fluid, and the exceeding velocity of the latter became manifest to the eye. The rotary motion is not, however, the uniform result of such experiments.

There will often be seen a scalloped figure, with a greater or less number of re-entering curves destroyed and reproduced with astonishing rapidity and regularity. A slight humming noise was also occasionally perceived, as the liquid was alternately raised and depressed by this species of movement. Gravity was here put in equilibrium with the repulsive force of caloric, and as the equilibrium must, from the nature of the fluid, be *unstable*, there was a constant effort of those parts of the fluid which happened for a time to be less resisted than others by the heat, to obey gravity, and come nearer the service; but, as they descended, they came to be, in turn, more vigorously resisted, and sent up again with energy, even beyond the distance of equilibrium. A new descent was the consequence, and the alternation once established, was easily maintained by the momentum of the fluid, and the perfect elasticity of the spring on which it constantly impinged. This phenomenon is similar in character, and probably admits a similar explanation to that of an experiment of Mr. Faraday, in which a segment of a cylinder of metal has a narrow groove cut longitudinally along the convex side, forming two *straight edges* one or two-tenths of an inch asunder. If this segment, heated to four or five hundred degrees, is laid on another polished metallic plane surface, so as to rest upon the two edges, it will soon acquire a rapid oscillatory motion, bringing the two edges alternately in

contact with the plane below. This oscillation may be sufficiently rapid to cause a ringing or humming noise. In this case the radiation is from the oscillating body *downwards*, while in that of a fluid undergoing evaporation, it is from the fixed plane to the oscillating body or liquid *upwards*.

The temperature of the liquid while resting over the red hot surface of iron, was found to be 210°.

4. The resistance to actual contact, which is furnished by heat in both the cases just mentioned, is exemplified in many processes of art. The attempt to perforate a bar of hot iron with a cold steel *bit*, will present a sensible illustration of this point. The resistance may, however, by mechanical pressure, be overcome to such an extent as to bring the solid in one case, and the liquid in the other, into such contiguity as to restore, in some degree, the adhesion of the liquid or the abrading power of the steel. The pressure may be applied directly to the liquid when placed upon a metallic plate, by means of another smooth metallic surface pressed immediately upon the drop of liquid. Smart vigorous explosions may be thus produced, similar to the well-known cracking under a smith's hammer, which has been dipped in water, and then applied to a hot bar of iron, or to the over-heated face of an anvil.

The pressure of an elastic gas or vapor may, in like manner, be employed to urge the liquid into contact with the metal; and, it is evident, must become at every instant the more effectual, both as the pressure is increased by the accumulating mass of steam, and as the temperature is diminished towards the point of most rapid action. It will be understood that the calculation formerly made respecting the power which an over-heated boiler of given dimensions could produce, was intended only to exhibit the *amount of atmospheric steam*.

5. It becomes interesting to inquire whether any other liquid than water is affected, in a similar manner, by the over-heated metallic surface. The trial soon convinced me that, in regard to alcohol, at least, the same general phenomena take place. It may at first appear singular, that a given portion of this liquid (the boiling point of which is at 174° Fahr.) should require for its evaporation a longer time when laid upon a plate of iron at 400° or 500°, than when poured into the hand of the experimenter, the temperature of which is not above 98°. Such, however, appears to be the fact. When one-sixteenth of an ounce of alcohol was laid upon the centre of an iron basin, heated to at least 500°, the time of its final disappearance was one hundred and forty-five seconds; while an equal quantity of the same spirit required but ninety seconds to evaporate it from the palm of the hand. It is true, that, in the latter case, the extent of surface occupied by the spirit was unavoidably greater than that on the iron. The liquid was diffused by capillary attraction, or perhaps by its attraction for heat, over the whole surface of the palm, notwithstanding the efforts to confine it to a single spot. At a temperature when the iron became barely red in the dark, the time of disappearance was from one hundred and ten to one hundred and twenty seconds.

The next thing was to determine the time requisite to vaporize one-sixteenth of an ounce of alcohol, *when the metal was at a temperature to give a maximum energy of action* between it and the spirit. By several trials for this purpose, it was found to be three and a half seconds. The *greatest length of time* during which the same quantity had been found to remain, was one hundred and fifty seconds. Whence it appears, that the

relation between the two is $\frac{3 \cdot 5}{150} = \frac{7}{300}$, or $\frac{1}{43}$ nearly. The only remaining question was the actual temperature at which the spirit disappeared in the least time. For this purpose, recourse was had to the bar with mercurial reservoirs and cups already described. On raising the temperature to 312°, where water had been observed to be most rapidly vaporized, it was manifest that the alcohol was clearly and strongly repelled.

The temperature was then lowered to 280°, when occasional signs of adhesion were manifested, and a corresponding diminution in the time of evaporating a given quantity of liquid, was the result.

By lowering the temperature of the iron to 260°, the time was again perceived to increase on account of a *deficiency* of heat. By thus passing and repassing several times between 260° and 280°, the limits of range became circumscribed between 270 and 278°, and, finally, the point of most vigorous action seemed to rest at 274°, the arithmetical mean of the above mentioned limits. This, it will be recollected, is 100° above the boiling point of alcohol. It will be observed, also, that this is exactly as much above its boiling point as the temperature of most activity on water is above the boiling point of that liquid.

6. An allusion has already been made to the opinion of some writers, that the repulsion of a liquid from metal begins at the temperature of incandescence, and increases as the temperature rises. The facts already detailed in this paper, will serve to show that the former opinion is wholly without foundation. Indeed, when we reflect for a moment on the nature and cause of that diminution of the liquid which takes place after *vaporization has ceased through an excess of temperature*, we must perceive that, as the effect is an *evaporation*, due to the radiation of heat, the rapidity with which the latter will disperse a given quantity of water must be proportionate to the *tension* of the heat at the radiating source; that is, the surface of the metal. Evaporation must commence where vaporization ceases, and the former must be slow when the tension is barely sufficient to elevate the liquid out of the sphere of contact, or of contiguous attraction. This cannot, however, prevent an increase of rapidity, when the tension of the source is sufficiently elevated to allow the radiated heat to communicate temperature to a *transparent medium*.

To place the matter beyond a doubt, the iron basin already mentioned, was used. When exposed to the white heat of a forge-fire, a given weight (one-eighth of an ounce) of water was evaporated in sixty seconds. At the bright red heat of an anthracite stove, eighty seconds were required to produce the same effect. When exposed to an open grate of anthracite, in such a manner as to maintain the centre only of the basin at a very faint red heat in the dark, the time was extended to three hundred and fifteen seconds.

Another comparison, made upon portions of water of one-sixteenth of an ounce each, gave the following results: On the metal, at the bright red heat of the heat of the stove, the water lay sixty-six seconds; on the centre of the basin dull red, as before, in the dark, it continued one-hundred and eighty-three seconds; while, over a spirit lamp, the metal being constantly black, and the temperature probably not above 600°, it remained two hundred and eighty-six seconds.

In all the above experiments, the heat was constantly supplied, and the temperature may be regarded as having been uniform during each trial. Hence, the opinion that repulsion increases with the temperature, appears

not to be sustained. When the temperature has decidedly surpassed the point where contiguous attraction can take place, every elevation of temperature is attended with a corresponding diminution of time required for evaporation.

In order to illustrate more fully this branch of the subject, a series of experiments was made with the iron basin placed over a coal fire, and supplied with doses of one-sixteenth of an ounce of alcohol, sp. gr. 854, (32,5° Baume.) The first experiment was made at a temperature about 400 to 500 degrees.

The following was the succession.

Exp. 1	142″	Exp. 3	140″
2	145	4	117

The temperature of the metal continued to rise notwithstanding the application of the successive portions of spirit, and, as the time for each experiment was obviously decreasing through an *excess of temperature*, the basin was removed from the fire, and allowed to stand for some time, until it was cooled below the point of *minimum activity*. It was then again placed upon the fire, and when the fifth portion of liquid was placed upon it, exhibited symptoms of a slight tendency to attract the latter. The sixth experiment was made after sufficient time had elapsed again to permit a rise of temperature.

Exp.	5	87″	Rapidity increased by deficiency of temperature to maintain the repulsion uninterrupted.
	6	150	Iron kept some time on the fire without liquid before this experiment.
	7	143	
	8	134	
	9	128	
	10	120	Very faintly luminous in the dark.
	11	115	Redness gradually increased.
	13	113	
	14	100	
	15	95	
	16	82	

The surface of the basin about the spirits exhibited, when the room was darkened, a very distinct luminousness, like a faint lambent flame, owing, probably, to the vapor being heated nearly to redness at the moment of production. A similar appearance had been observed in the vapor of water, produced from metal at a white heat.

Having now removed the basin from the fire, the experiments were continued, and the time was observed to increase from eighty-two seconds to one hundred and five, and then to one hundred and thirty-five, after which it began to diminish, as the establishment of cohesion between the liquid and the metal became more decided, thus:

Exp. 17	105″	Exp. 20	17[illegible]
18	135	21	10[illegible]
19	90		

The above series of experiments is in accordance with several of those made upon water, where the initial temperature of the iron was very great, and the mass sufficient to supply heat, of a high tension to the evaporating surface, for a considerable length of time after being removed from the fire.

This was the case in the *first*, *second*, *fifth* and *eighth* series in the *second course* on the rate of decrease. In those cases, the times exhibited either a succession of numbers nearly equal, or an actual increase during the first five or six experiments of each series. This is particularly remarkable in the eighth series, of which a projection has been given. The order of magnitudes, for the first six experiments, beginning with the highest, was followed in that projection, merely for the purpose of exhibiting the extremes of retardation, both by excess and by deficiency of temperature, in the production of vapor. The reader will perceive, however, that the actual order of occurrence of these six experiments, which began at a *white heat*, and lasted, including intervals, 218.7 seconds, was 27.5, 28, 44, 39, 30, 33. It needs hardly be stated, that the idea of *instantaneous* action between iron and water derives no confirmation from any of the foregoing series of experiments.

Description of an instrument called the steam Pyrometer.

A careful attention to guard the containing vessel in which we produce steam from boiling water by means of metal, or other solid or liquid bodies capable of being heated in open vessels above 212° Fah. will enable us to measure, with great accuracy, the quantity of heat which such solid or liquid body expends in cooling, from the temperature at which it is first put in, down to the boiling point of water.

The mode of calculating the temperature when the specific heat is known, has already been given. The only point of much difficulty in rendering the formula heretofore stated, directly useful in pyrometry, are, 1, the necessity of defending the vessel in which the steam is produced, from the effects of radiation and conduction during the operation; 2, the obviating of loss in transferring the hot body to the liquid through the air; 3, the means of obtaining and marking the true boiling point; and, 4, the means of speedily and accurately weighing the liquid, and showing how much has been evaporated during an experiment.

To these causes of inconvenience, may be added, that which results from the low specific heats of some of the substances to be employed as standards. Such are several of the metals, as platina, gold, &c. It is obvious that the method of plunging the body, of which we would know the temperature, directly into boiling water, can be adopted only with regard to solids, which remain unchanged after being quenched in water, and which are not capable of imbibing the fluid, on account or porousness, or such physical characters as would render them liable to combine chemically with the water.

When we have to deal with liquids of which the temperatures extend beyond that of boiling mercury, that is, of mercury boiling in vacuo, (which must necessarily limit our use of the mercurial thermometer,) we must either pour such liquid into the boiling water, if a melted metal which will not undergo a change in that method of cooling, or must enclose it in a suitable vessel, extremely thin, and of materials to sustain the action of water upon it, or must immerse in the hot liquid or the melted metal, a mass of some other matter capable of preserving its form under a heat greater than that of the liquid. The latter method is, on several accounts, to be preferred. First, we may always use the same amount of hot matter to produce the

STEAM PYROMETER BY W. R. Johnson.

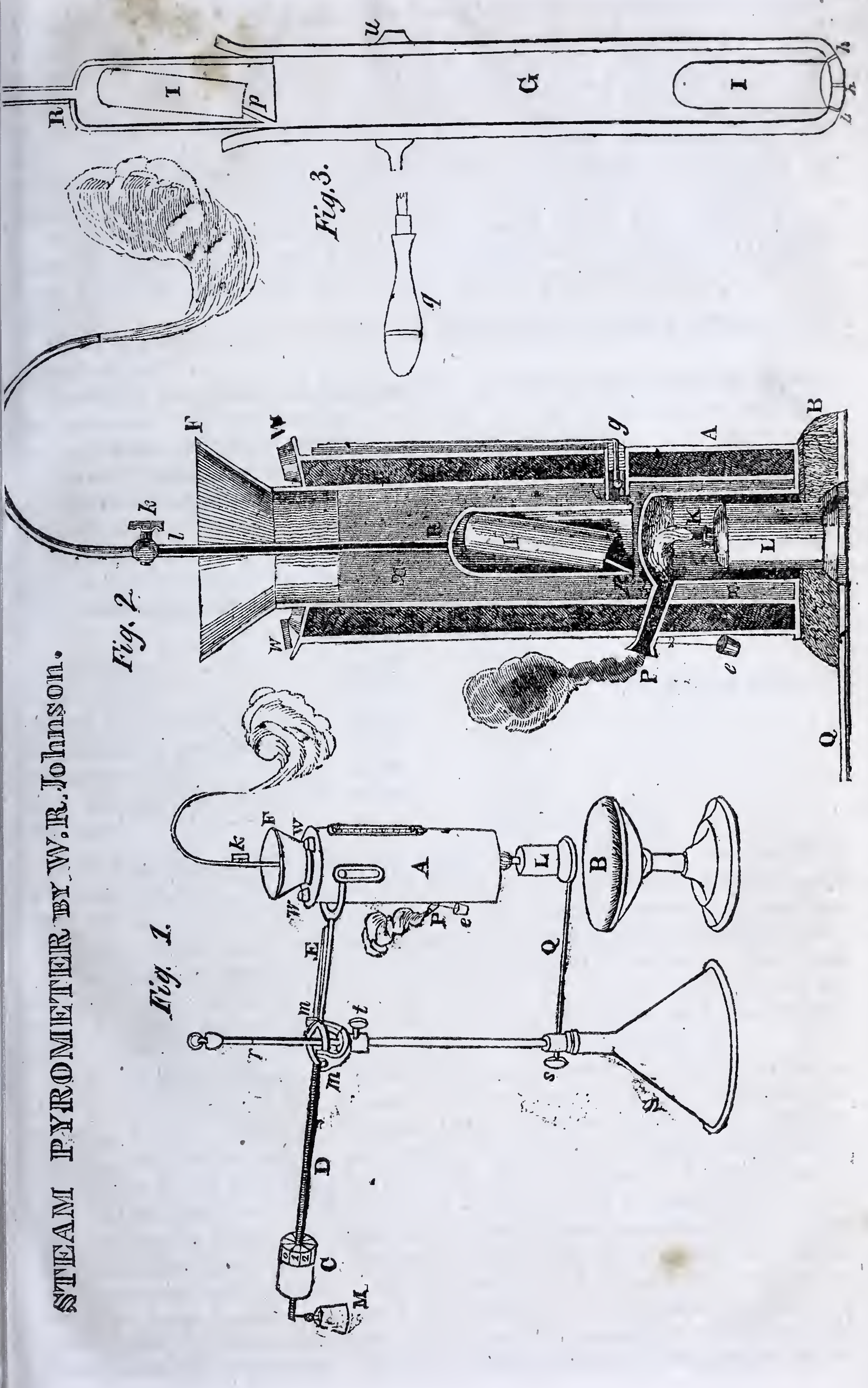


Fig. 1.

Fig. 2.

Fig. 3.

vapor, and consequently compare the actual heats of two melted masses without calculations. Second, the hot body may be directly applied to the water without the intervention of any enclosing vessel. Third, the pouring of the hot metal or liquid into water might not always be convenient or safe, as for example, when the latter is of greater specific gravity than the former. When, for example, oil is laid, at a very high temperature on the surface of water, the sudden ebullition of the water would be in danger of causing an explosion that would project the oil upwards with great force.

When we plunge a solid into a melting mass of metal, and allow it to remain for some time, it will acquire the temperature of the mass of melted matter, but the *solid* must have certain peculiar properties to fit it for this purpose.

First, it must not melt at a lower point than that of the fluid which it is intended to test.

Second, it must allow of being quenched in boiling water from the highest temperatures employed, without cracking, scaling, oxodyzing, or undergoing any augmentation of weight by absorbing the liquid.

Third, it must have as high a *specific heat* as practicable.

Fourth, it should be capable of being easily wrought into the peculiar form required for the instrument with which it is to be used.

Among the substances best adapted for the purpose, are the following: against each of which the specific heat is marked, together with the name of the author whose determination has been followed.

	Spe. heat.	Authorities.
Crown glass,	.2000	Irvine.
White glass,	.1870	Wilcke. (.1770, Pet. and Dul.)
White clay, burnt,	.1850	Gadolin.
Black lead or plumbago,	·1830	Do.
White cast iron,	.1320	Do.
Soft bar iron, spe. gr. 7.724,	.1190	Do.
Platinum,	.0314	Petit and Dulong.

The chief parts of this instrument are a boiler, A; (Fig. 1.)—a stand, S;—a balance beam, D, for weighing the boiler and its contents;—a lamp, L, to heat the water, and to maintain ebullition between experiments;—a receiver, R, (Figs. 2 and 3,) and a cylinder of metal, I, to be employed as a *standard*.

The boiler is formed of two concentric cylinders of copper. The inner cylinder is two and a half inches in diameter, the exterior one is four inches, leaving a space of three-fourths of an inch to be filled with finely powdered charcoal or lampblack, seen at O, in the section, (Fig. 2.)

The *interior* cylinder rises half an inch above the exterior, which is twelve inches high. The former is then expanded into a funnel-shaped mouth, F, five inches in diameter at top, and two inches perpendicular height, intended to receive and return any portions of water which might be thrown up by ebullition, but not converted into steam. From the lower part of the apparatus, a third concentric cylinder, K, rises about three inches and one-fourth, where it terminates in a conical head furnished with a pipe, P, passing obliquely upwards through the two cylinders before mentioned, and firmly soldered to both. The purpose of this third cylinder is to receive the lamp, L, and to expose a large surface to the action of its flame. *e* is a stopper intended to close the pipe, P, when the lamp is withdrawn and the experiment in progress. E is an index attached to the support *m*, in

such a manner that the point E may be elevated or depressed a few degrees, to correspond to the position of the beam D, and save the adjustment by weights *before* an experiment. The cylinder of lead C, is movable along the rod by means of a screw thread, cut the whole length of that arm. This mode of adjustment admits of the greatest accuracy, and is liable to less delay than the sliding weight. By means of the tightening screw, *t*, the support *m m*, may be placed at any convenient height on the rod *r*, and by means of *s*, the lamp L, may be loosened and caused to revole horizontally when the metal is about to be immersed; in which case the boiler will be for the time depressed, and will rest on the cushion B, which is composed of hair's fur, covered with soft flannel, to defend the bottom from the access of air: the stopper *e*, is a further safeguard against the same source of loss. A thermometer *g*, bent at right angles, passes through the two concentric cylinders, having the bulb directly exposed to the water within, but defended from injury by a projection of its tube *o*, a short distance beyond the inner cylinder.

The receiver R, is about four inches in height, and one and a quarter in interior diameter, furnished above with a tube *l*, and a stop cock *k*, to convey away the steam, and to carry it, when required, into a vessel of cold water. The only direct access of the water *x*, to the hot body I, when in place, is through the *bottom* of the receiver. If the stop cock be closed, the steam will soon fill all the surrounding space, and keep the water down quite to the lower edge; but if the cock be opened, the steam, finding an outlet, will rise, and the water will follow, and again produce a large quantity of vapor. It will generally be found expedient to allow a moderate discharge only at the mouth of the pipe, and to cause the greater part of the action to take place through the metal of the receiver R. The only uses, indeed, of this part of the apparatus, are, 1st, to receive, without loss of heat, the standard piece, I, and deposite it in the water, without coming in contact with the exterior air; and, 2d, to prevent the dispersion of the water by the extreme rapidity of its action, particularly towards the close of the operation. The pipe of R, is wrapped with flannel.

The manner of transferring the standard-piece is seen in Fig. 3, where G is a cylindrical, or slightly conical recipient, either entirely closed, or having a few orifices, *h*, *h*, *h*, at the bottom. This recipient is to be formed either of iron, copper, silver, platina, plumbago, wedgewood ware, or crucible clay, according to the heat to which it is to be exposed, or the materials into which it is to be plunged. It will often be found expedient to protect the cylinder I, from the direct action of the fused metal, of which we would ascertain the temperature, otherwise there might be an adhesion of some portion of the melted mass which would vitiate the experiment. When the body, I, has been heated to the requisite degree, and is to be transferred to the receiver, R, the container, G, is laid, by means of the handle, *q*, *u*, on some convenient support; R is then inserted at the mouth, so that the hook, *p*, shall be on the same side with the handle; G and R are then inclined, so that I may slide from the bottom of G into R; the latter is then rolled over upon the side, *p*, when the concave base of I will be received upon the hook, and the cylinder will take the position indicated by the dotted figure, the moment R is raised to a vertical position.

It may then be plunged in an instant into the boiling water, as seen in Fig. 2. The quantity of vapour produced, is shown by the weights, W, *w*, which it may be necessary to add to A, in order to restore the position of

the beam, so that the index E, shall again point to an engraved line on the side of the bar.

The receiver R, may be kept in the water when not required for immediate use, and be weighed with the liquid both before and after the experiment. By this means, its temperature will be the same as that of the water, and no calculation necessary.

The lamp L, instead of being removed, by revolving, to allow the generator A, to rest on the cushion B, may rise through the centre of that cushion, which may, in turn, be supported by the rod attached at *s*. This arrangement is seen at B, Fig. 2, where the rod Q sustains a small circular platform and cushion, as well as the lamp, L. The advantage of this arrangement is the saving of time, and the only inconvenience, that the lamp must be relighted after each experiment, as it will be extinguished by closing P, and preventing the access of air from below to K. It must obviously not be kept burning under the generator during the experiment.

Instead of employing weights, as at W, *w*, to reproduce the counterpoise, or show the equivalent weight of steam produced, I have graduated one *end* or *base* of the counterpoise C, by radiant lines, and caused to be removed a segment of about 60° along the screw D, through its whole length, so as to present a vertical plane surface, on which to form a scale: the graduations of this scale, are, of course, regulated by the distance apart of the threads of the screw: the weight of the counterpoise is such that one revolution on the thread produces a difference of one-hundreth of a pound at the boiler end of the beam. The periphery of C is then graduated into one hundred equal divisions, (indicated by the figures 0, 1, 2, 3, &c.) so that, as a complete revolution of the counterpoise towards the end of the rod, marks an increase of one-hundredth of a pound in the weight of water put into A, so a corresponding movement in the reverse direction, compensates for the same amount of loss by evaporation; and a movement through one of the *centigrade* divisions only, or one-hundredth of a revolution, as marked on the end of the cylinder, of course, indicates one-hundredth of the above amount, namely, one-ten-thousandth of a pound. If greater exactness were required, it might be obtained either by making the threads at a less distance apart, or by diminishing the counterpoise C, and substituting for a part of its weight a fixed weight, M.

I have found the apparatus sensible to the fourteen-thousandth of a pound, or half a grain, when fully charged for use, that is, when the boiler contained at least sixteen ounces of water.

The arrangement above indicated may be varied to suit the different purposes to which the instrument may be applied, and the standards will be different according to the temperatures to which they must be exposed. If the substance, of which the temperature is to be ascertained, can with safety be plunged beneath the surface of boiling water, without causing either chemical change or variation of specific gravity, this direct action of the substance is doubtless to be preferred to the intervention of any second substance as a standard. The quantity, or number of *therms** of heat present, in a given weight of the substance in question, will then be known; and if we know or can determine the specific heat, we may calculate the temperature as already indicated. I have, in this manner, proved the quantity of heat present in melted iron. Practical men may, possibly, from occasionally

* See Ch. Dupin. Mechanique, tome 3. p. 353, et seqq.

experiencing the tremendous effect of generating a quantity of steam from the moisture of their moulds, imagine that the experiment of pouring melted iron into a vessel of boiling water will be attended with danger. But I can assure them, from repeated trials, that it is perfectly safe. Plunge into a bucket of water, a common small iron kettle, supported on feet: pour into this, when completely immersed, any convenient quantity of melted iron; the ebullition from the surface of the melted mass will be at first very slow, or scarcely perceptible, while, from the outside of the kettle, it will be very vigorous. The whole will subsequently exhibit the same effects as are perceived when a piece of cast iron is immersed at a bright red heat.

The following experiment was made in August, 1831. Twelve ounces of melted iron were poured into about six pounds of water, at 212°. The result was, eight ounces of steam produced. In order to calculate this case, and obtain the actual *power present in the state of heat* at the time of the immersion, we have to multiply the weight of steam by its latent heat, say 990°, which gives 7920°; this divided by the weight of metal, (twelve ounces,) gives 660 for the number of ounces of water, which one ounce of the metal would have heated one degree in cooling itself down to 212°. But, as the *temperature* of the metal is the thing required, we must divide the above by the specific heat of cast iron, say $\frac{1}{8.25}$ or .1212, which gives $660 \div .1212 = 5445°$. But it will be recollected that a portion of this must be regarded as the *latent heat of melted iron.*

In order to show what the latent heat of cast iron *is*, we may adopt the plan of taking from a mass of melting iron a lump not actually liquefied, quench it, and observe the weight of steam produced. Again: pour from the same mass a portion of the liquefied metal, and ascertain how much *more* steam, for the same weight, is given by the latter than by the former. The same proceeding may be adopted for all other metals and their alloys.

The following experiments and calculations will show the mode of applying the steam pyrometer:

1. A cylinder of cast iron, weighing 5668 grs., was heated to redness. It was then placed within the receiver, and instantly plunged into boiling water, previously accurately weighed; after the entire cessation of ebullition it was withdrawn, and the deficiency supplied by weights. The heat had been a moderately red heat;—now, as cast iron has a specific heat of about .1212, this multiplied by 5668, will give the equivalent weight of water =687, which, heated to the same degree, might produce the same effect. In the case just stated, the quantity of water found to have been evaporated was 674. Hence 674 multiplied by the latent heat in steam, (=990° Fahr.,) gives 667260°= the grains of water which would be heated one degree by condensing the steam now generated. But as the iron was equivalent to only 687 grains of water, it must have been heated as many degrees above 212° as 687 is contained times in 667260°, which is 971.2 times; hence this number added to 212° will give the temperature of the iron, expressed in degrees of Fahrenheit's scale, equal to 1183.2.

2. Another experiment, conducted in the same manner, and with the same cylinder, but at a cherry red heat, gave 945 grains of steam. By applying to this case the principle of the formula, as before, we have, as above, $5668 \times .1212 = 687$, for the equivalent of the iron in weight of water; and $945 \times 990 = 935550 =$ the grains of water which would be heated one de-

gree by the condensation of the steam produced. Then 935550÷687=1362= the number of degrees which the iron must have lost in producing this effect, while it came down from its initial temperature of redness to 212°. To this again we add 212°, and obtain 1574° for the actual temperature.

3. A ball of cast iron, weighing 1665 grains, was heated to a bright red, and gave 230.2 grains of steam. Here 1665×.1212=201.8= the equivalent weight of water, which, if heated to the same temperature, would have produced the same effect, viz. 230.2×990=227898. Now this divided by 201.8 gives 1128= the degrees above boiling point, at which the temperature was at first, or 1128+212 is equal to the actual temperature above the zero of F., viz. 1340°.

4. With the same ball a second experiment gave 139 grains of steam. Hence 990×139=137610, and this divided by 201.8=681.8, and to this add 212, and we have 893.8 for the temperature at first.

5. The next experiment was with a cylinder of wrought iron, weighing 6110 grains, having a specific heat of .1100, and consequently being equivalent to 6110×.11=672 grains of water. The observed heat was a moderate red, and the loss in weight of water 780 grains, whence the temperature must have been (780×990) ÷672=1149+212=1361° Fah.

6. The same cylinder was again employed and raised to a bright red, so as to "scale" on exposure to the air. It then gave 989.6 grains of vapor; consequently, its heat must have been $\frac{989.6 \times 990}{672}$ =1462° above the boiling point, or 1674° of Fahrenheit's scale.

The process of calculation may be much simplified when the specific heat of the *standard piece* has been accurately ascertained and its equivalent of water found; for we have then only to multiply the weight of steam produced by its latent heat, or heat of elasticity, and divide by that equivalent. This is the same as multiplying the *weight of steam* by a known constant fraction. In the fifth experiment, above cited, the equivalent of the metal is 672 grains of water, so that the constant fraction by which to multiply the weight of steam actually generated in any given experiment with that cylinder of iron, in order to obtain the temperature above 212°, is $\frac{990}{672}=\frac{165}{112}$, or (in decimals) 1.4732. This number, multiplied by 780, gives the degrees 1149, as before. The process may be farther abridged, by performing the multiplication by logarithms; in which case we should have the logarithm of 1.4732 constant, and hence it would only be necessary to find in the table the logarithm of the grains of steam, add to it said constant quantity, and find the *number* standing against their *sum*, for the temperature above 212°.

Thus, the logarithm of 1.4732 is	.168259
To which add the logarithm of 780=	2.892095
And we obtain the logarithm of 1149°	=3.060354

It will be no less easy to solve the same problem by means of a Gunter's scale and a pair of compasses. The distance from 1 to the constant fraction, (1.4732 in the above case,) on the *line of numbers*, will reach from the number of grains of steam to the temperature, in degrees Fahr., above 212°.

We might, instead of determining the specific heat of the *standard mass* by the ordinary methods, first heat it to a known temperature in boiling mercury, in oil, spirits of turpentine, melting zinc, lead, bismuth, tin, or

any convenient alloy* of these metals, and then observe the quantity of steam it produces in cooling down to 212°. The actual temperature of the liquid being known by observation, and the quantity of steam by weight, every other quantity of vapor given by different temperatures of the same standard mass, will be produced by a proportionate quantity of heat. It will be seen that this method of proceeding takes no account of differences in specific heat at *different temperatures*. It comes at once to a simple expression of the heating power of a body measured by a *single effect* of the heating principle, that of conferring the elastic form on water already raised to the boiling point.

It will readily be conceived that the question of specific heats, of expansion, and contraction, and, of course, the variable rates of expansion at different temperatures, might be wholly disregarded, if we had an invariable standard by which to measure the portions of heat that may at any time be present in a given portion of matter. The latent heat of vapor supplies this standard. The following are some of the different results which have been obtained by those who have made experiments on this subject.

Latent heat in vapor.	Determined by
950°	Watt.
945	Southern.
1000	Lavoisier and Laplace.
1040.8	Rumford.
955.8	Despretz.
Above 1000	Thomson.
1000	Ure, (corrected result.)
Mean 984	

I have in the preceding calculations assumed the latent heat at 990°. Should the results of Dr. Ure, which appear to have been made in a manner as unexceptionable as any yet published, be confirmed and established by other philosophers, the facility of making calculations, such as I have above presented, will be increased, and the usefulness of the principle in pyrometry more fully established.

NOTE.—The experiment on melted iron, on page 138, is offered *chiefly* as an *illustration*. The apparatus then at hand did not admit of all the exactness which the case allows, still the result is believed to be nearly correct.

* The alloys of tin and lead are very convenient for this purpose. Their melting points, as determined by M. Kupffer, (See Ann. de Chim. et de Phys. XL. 302; and Thomson on Heat and Electricity, p. 174.) are as follows:

Alloy of Tin		Lead	Point of fusion.
1 atom	+	1 atom	466°
2 "	+	1 "	385
3 "	+	1 "	367
4 "	+	1 "	372
5 "	+	1 "	381

The alloy commonly employed by tin plate workers is I believe composed of 1 tin, + 2 lead. The mean of several trials with that alloy have convinced me that its melting point is 385°.

No. 28.

Copy of a Report made to the Secretary of the Treasury, by Dr. John D. Craig, of the Patent Office.

Water is a fluid too well known to require any description. When subjected to a temperature at or below 32° of Fahrenheit's thermometer, it becomes a solid body, and remains such until again exposed to a higher temperature than that of 32°. Ice, or water in a solid state, like all other bodies, in general, contract in volumn as its temperature is diminished; and expands as its temperature is increased. But when surrounded with a higher temperature than 32°, it rises to that temperature, and then becomes stationary, and immediately begins to assume the liquid state. No elevation of temperature in the surrounding bodies, or medium, will raise it, in the smallest degree, till the whole mass is reduced to the liquid state: it then begins to increase, and continues until it exhibits that of the surrounding bodies. As its temperature is augmented above the freezing point, its volumn diminishes till it arives at about 40°, thereby presenting an apparent exception to a general law of nature. Having passed that point, its magnitude increases, though not exactly in proportion to its increase of temperature: the expansion increasing in a greater ratio than that of the temperature, until it arrives at 212° under the usual pressure of the atmosphere. There its temperature again becomes stationary, let that of the surrounding medium, or bodies, be ever so much higher. Another change of state, however, immediately commences. The water is gradually transformed into an invisible elastic fluid, of the same temperature,(212°) with the water; nor can the application of the most intense heat increase the temperature of either the water or the elastic fluid, as long as they are exposed only to the usual pressure of the atmosphere.

The elastic fluid, so formed, is denominated *steam*, and it possesses all the mechanical properties of atmospherical air, and other elastic fluids. It is invisible; expands as the surrounding pressure is removed; and its expansive power, or elasticity, is directly proportional to the force by which it is compressed.

The *natural cause*, whatever may be its *nature*, which produces in bodies a capacity for communicating the sensation of *heat*, is denominated *caloric;* and the degree of this heat, indicated by a suitable graduated standard measure, (thermometer,) is denominated temperature. Now, if equal weights of ice and water, both at the temperature of 32°, be placed in an atmosphere at 47°, the water, in half an hour, will indicate a temperature of 39°, an increase of 7°. The ice will require twenty half hours in this case to be dissolved into water, and exhibit no increase of temperature; but, in one half hour more, ascend to 39°. During those twenty half hours, caloric must flow into the ice with the same velocity as into the water during the one half hour; consequently, twenty times seven, or 140° of caloric disappear during the liquefaction of the ice. Hence, it is concluded that caloric is the *cause* of fluidity, as well as of heat and temperature; and that, while ice is transformed into water, as much caloric combines with it as would raise the temperature 140°.

Again, if a given quantity of ice at 32° be mixed with an equal weight of water at 172°, the result will be the weight of both in water of the temperature of 32°. Here 140° of temperature have disappeared from the water without increasing that of the ice; it has only changed the ice into water.

Hence, again, we conclude that water is ice, combined with 140° of caloric. This caloric is, therefore, said to be latent, and, on the hypotheses that caloric is a *fluid,* is supposed to be chemically combined with the substance of the ice.*

If this water be placed in a medium below 32° of temperature, its temperature will be gradually diminished till it arrives at that point. It will then become stationary, and remain so till the whole is congealed, and, during the process, give out the precise quantity of caloric which had disappeared during the liquefaction. It will then sink to the temperature of the surrounding medium.

When the temperature of water is raised to 212°, it becomes, as stated above, stationary, and is transformed into steam. To discover the cause of this phenomenon, let one part of steam at 212° be mixed with six parts by weight of water, at 62°, and the result will be seven parts of water at 212°. Here the steam is reduced to water, without any reduction of temperature; but it has given out as much caloric as raised six times its weight of water 150°, and, consequently, would be sufficient to elevate one part to six times 150° or 900°.

From this, and similar experiments, which produce the same result, it is inferred that steam, at 212°, and under the ordinary pressure of the atmosphere, is water at 212°, chemically combined with as much caloric as would raise the water it contains 900°, if it were to continue in the state of water. Accordingly, when water is confined in Papin's digester, and raised to 300° or more of temperature, no steam is generated; but, on opening the valve, steam is instantly formed, and rushes out with violence, but neither the steam, as it escapes, nor the water that remains in the digester, indicates a higher temperature than that of 212°. Hence may be deduced the following rule:

Let A = weight of steam at 212°, and a = do. water at T temperature, then will $\frac{A}{A+a} \times 900 + 212 - T + T$, express the temperature of the mixture, if not greater than 212°; but if greater, say, as 900° is to said excess, so is A + a to a fourth number, *expressive of the quantity of steam uncondensed.*

Steam at 212° occupies about   times as much space as when in water at the same temperature, and under the usual pressure of the atmosphere. Its elasticity, or expansive power, is then equal that of atmospheric air, (14½ pounds per square inch;) nor can its expansive force or temperature be augmented while only compressed by the atmosphere. But if confined in close vessels, and its temperature increased above the boiling point, its elastic force will be increased in a much higher ratio than its temperature. On the contrary, if the atmospherical pressure be partly removed, the water will boil, and the steam be generated at a temperature below 212°. If wholly removed, the boiling point will be reduced to 212° — 145° = 67°.

* If A = oz. of water at T temperature, and A = do. of ice at 32°, then $T - \frac{140\,a}{A+a} =$ temperature of the mixture; also, as A : a :: 172 — T : T — 32.

The expansive force of steam, as connected with temperature, is found, by accurate experiments, to be as in the following table:

Temperature.	Elastic force in in. of mercury.	Elastic force in lbs. pr. sqr. inch.	Temperature.	Elastic force in in. of mercury.	Elastic force in lbs. pr. sqr. inch.
° 212.	30.000	14.74	255.	67,250	33.03
216.6	33.400	16.41	260.	72.300	35.51
220.	35.540	17.46	264.9	77.90	38.26
221.6	36.700	18.03	270.	86.30	43.39
225.	39.110	19.22	275.	93.48	45.92
226.3	40.100	19.70	280.	101.90	50.05
230.	43.100	21.27	285.2	112.20	55.11
234.5	46.800	22.99	290.	120.15	59.01
238.5	50.300	24.71	295.	129.	63.36
240.	51.700	25.40	300.	139.70	68.62
245.	56.340	27.67	305.	150.56	73.96
248.5	60.400	29.67	310.	161.30	79.23
251.6	63.500	31.19	312.	167.00	82.03

It should be kept in mind that the density and elasticity of steam cannot, like that of atmospheric air, and other permanent gases, be increased by mechanical pressure, unless its temperature be augmented at the same time; otherwise a portion of the steam, corresponding to the compressing force applied, will be condensed into water, so that the elasticity of the remaining steam will still correspond with its temperature, as in the foregoing table. The fact, however, is, that in all cases of mechanical pressure on steam, unless it be surrounded by very good conductors of caloric, an increase of temperature must take place, for that portion which may be reduced by the pressure to the state of water, will give out 900° of caloric, and these being diffused, partly through the remaining steam, will increase its temperature and elasticity, till it becomes a counteracting force to the external pressure. Hence it follows, that if steam be confined by bad conductors of caloric, external pressure will diminish its quantity, but augment its force.

When steam is brought into contact with red hot iron, it is decomposed, or resolved into its constituent parts; oxygen and hydrogen gas are formed. The first of these enters into combination with the metal, the other occupies a space under the same pressure, and at the same temperature, somewhat greater than the steam from which it is generated, and, consequently, its elastic force will exceed that of the steam from which it was generated.

The specific gravity of water at 60° being denoted by unity, that of atmospheric air, at the same temperature, under the usual pressure, be represented by .00123, oxygen gass, by .001353, and hydrogen, by .0000898 — also, the ponderable part of water is known to consist of fifteen parts oxygen and two of hydrogen.

$$\text{Therefore, as } \left\{\begin{matrix} .001353 \\ .0000898 \end{matrix}\right\} : 1 :: \left\{\begin{matrix} \frac{15}{17} \\ \frac{2}{17} \end{matrix}\right\} : \left\{\begin{matrix} 652 \text{ of oxygen,} \\ 1310 \text{ of hydrogen;} \end{matrix}\right.$$

the respective spaces filled by those gases, when generated from water, filling one such space, a cubic inch for example. If, therefore, a cubic inch of water was resolved into oxygen and hydrogen under the mean pressure of the atmosphere, these gases would occupy 1962 cubic inches at the tem-

perature of 60°. Now, the specific gravity of steam is to that of atmospheric air, both being at the same temperature, and under the same pressure, as $\frac{5}{8}$, or 625 to 1, and, consequently, to that of water, as 1 : 1.300; for as 8 : 5 :: 1 :: 625, and as 8 : 5 :: 00123 : 00077, the specific gravity of steam; hence, as 00077 : 1 :: 1 in. to 1300 inches—the space occupied by the steam generated from one cubic inch of water, both at the temperature of 60°. Now, since 1300 inches differs insensibly from 1310 inches, the space occupied by the hydrogen generated from the same quantity of water, and at the same temperature, it follows, since steam and all the gases are known to expand equally with equal increments of heat, that the spaces, and consequently the expansive forces of these quantities will always be nearly equal under the same pressure, and at the same temperature. Hence it appears that when steam comes in contact with red hot iron, whether it be decomposed, and the oxygen it contained be wholly combined with the iron, or the steam merely subjected to the increased temperature; in either case an instantaneous augmentation of elastic force will be endued, which, in all probability, will be equal that generated by the explosion of gunpowder. For, if this force be augmented 67 lbs. by increasing the temperature from 212° to 312°, what must it be when elevated to eight or nine hundred degrees, the temperature of red hot iron? But it is possible that both oxygen and hydrogen may be extricated, and remain some time mixed with the steam, and the experiments of Sir H. Davy prove that these gases will explode when mixed with five times their volumn of steam. Should this event ever happen, and we are not sufficiently acquainted with the laws of nature to assert the impossibility of such an occurrence, a most dreadful explosion would be the consequence. Let the impelling cause of the danger be what it may, the means of prevention are the same.

Let the boiler, when first constructed, be subjected to a strict examination in order to detect the slightest defect in either its structure, materials, or form, and afterwards to a proof or trial of strength at least ten times greater than that which it is to be *licensed* to bear when applied to its intended purpose. Let it be imperative that each boiler shall have two valves, one of which shall not be loaded beyond the licensed pressure of the engine, and excluded from the engineer, and all others except the proprietors or agents. Let certain means be adopted from preventing the surface of the water in the boiler from ever descending below a given mark. Let the proprietor be obliged to submit the boiler to a trial of its strength after every thirty days it has been in use; and let these trials be made, not by injecting *cold water* but by elevating the temperature of the contained steam until its force would raise the steam valve loaded with determinate extra weights. And, lastly, let the use of spirituous liquors, and of all species of gambling be prohibited whenever steam engines are employed, and it is confidently believed that every danger of explosion, except that from lightning, will be obviated.

No. 29.

Translation of a paper of the Academy of Sciences of Paris, entitled "Exposition of the Researches made by order of the Academy of Sciences, to determine the power of Elasticity of Steam at High Temperatures."

The Government having resolved to submit the steam engines to previous trials, and to subject their use to certain regulations of security, consulted the Academy of Sciences upon the means which, without impeding the development of industry, or the operations of commerce, would be best adapted to prevent the unfortunate accidents that may be occasioned by the explosion of the boilers.

This important question was examined by a special committee, whose report has been discussed and approved by the Academy of Sciences, and has been addressed to his excellency the Minister of the Interior.

Some months after (the 29th October, 1823, Bulletin of the Laws, No. 637,) appeared a royal ordinance, which made the measures proposed by the Academy obligatory, namely: the preliminary trial of the resistance of the boilers, intended to resist an interior effort of more than two atmospheres; the application of a framed (grillee) valve, laden with a weight properly determined, and which was not allowed to be augmented; lastly, the building of a wall around the boiler, the aim of which was to lessen the effect of the explosion, that could not have been avoided. But it is besides prescribed in it to use circular plates of a metal fusible at a temperature of 10° and 20° above the temperatures corresponding to the elasticity of the steam in the usual work of the engine.

Messieurs the Engineers of Roads and Bridges, or of the Mines, to whom the special execution of this ordinance was committed, soon perceived the impossibility of executing this last direction of the ordinance, with the uncertain data upon the force of the steam. We possessed indeed no table of a generally acknowledged accuracy that permitted to assign, without hesitation, the temperatures corresponding to the tensions of steam higher than the pressure of the atmosphere; and as the ordinance justly sets no limit to the power of elasticity that might be used in the engines, one would unavoidably have fallen upon cases entirely without the limits of the experiments hitherto tried, without going out of the limits of the usual practice.

The administration, informed of this new obstacle which it had not foreseen, addressed again the Academy, to obtain the documents desired by the engineers; but science possessed only some discordant measures under eight atmospheres, and for stronger pressures there were no results of direct experiments, (at the time when this was written, we were not aware of the memoir of Arzberger, which will be quoted hereafter,) nor any theory that could supply them.

In this state of things a preliminary report was made to the Academy, in which a table was presented to the administration, (Annals of Chemistry and Physics, t. 27, page 95,) extending to eight atmospheres, which had been deduced by interpolation from all the experiments that appeared to deserve the most confidence, either by the ability of the observers, or the nature of the methods of observation.

To go farther, and even only to leave no doubts upon the numbers contained within these limits, it was necessary to undertake experimental re-

searches, long, laborious, and costly. The Government invited the Academy to undertake this work, which was given to a committee which has had several changes in its composition during the long duration of its existence: it remained definitively composed of Messieurs De Prony, Arago, Ampere, Girard, and myself, (Dulong) who had the particular charge of the construction and establishment of the apparatus. The results of these, our researches, we now present to the examination and approbation of the Academy.

It appeared to us, that, to fulfil the intentions of the Government, it was necessary that the observations should extend to tensions greater than 20 atmospheres. No philosopher had as yet gone above 8 atmospheres, on account of the extreme difficulty of these kind of researches, and of the danger accompanying them.

Were we to limit ourselves, like some observers, and, among others, Mr. Robison, to the determination of the weight with which a valve must be laden to resist the effort of the steam, almost all the difficulties would vanish, and the apparatus would become very simple; but it is well known to what errors this kind of measures may lead. The committee was desirous to give to its work all the pefection possible, and required by the present state of the science: well presuming that, for a long time to come, no occasion would likely present itself to extend so far this kind of observation, it determined to apply the means the most laborious, but also the most exact—the direct measurement of the column of mercury capable of making equilibrium to the elasticity of the steam.

When this power does not exceed a small number of atmospheres, the direct measurement of the liquid column that it can support, presents no difficulty; but when it becomes necessary to support, in a glass tube, a column of mercury of from 20 to 25 meters elevation, the success of the experiment will of course be considered as very doubtful. We will soon show how we succeeded in vanquishing all the unfavorable chances.

The column of mercury might indeed have been supported by a metallic envelope, and thus guard it against the inconveniences of the fragility of the glass; but this would have limited the observations to terms previously fixed by the length of the tubes, because only the top of the column would have been visible, and only at the level of the extremity of each tube; besides, that the elasticity of the steam could not have been observed exactly, but at the moment when the apparatus would have reached the maximum of the temperature, which cannot always be brought to a certain determined degree. It may be seen that the difficulty of obtaining the coincidence of this maximum, with the limit imposed by the length of the tube, rendered this mode of proceeding almost impracticable.

We should fear to be led into tedious details, were we to state here all the reflections which led us ultimately to the construction of the apparatus we have employed. Every piece that composes it has been the object of serious examination, and it was only after having weighed, as much as possible, the most advantageous conditions of length, form, and relative position of each part, that we caused them to be executed by the best artists.

We will, however, here carefully give an exact description of the principal dispositions, that natural philosophers may judge to what errors our results might still be subject, under the supposition that our observations were well made.

The apparatus could have been reduced to two essential parts: a boiler to furnish the steam, and a glass tube to support the column of mercury; but

it was to be feared that the too rapid increase of the power of the steam, and particularly the instantaneous diminution which is to follow the opening of the safety-valve, would occasion strokes similar to those of the hydraulic ram, which would endanger the fragile parts, and occasion the spilling and loss of a considerable quantity of mercury, which prudence commanded to avoid. To avoid this, we have added a manometre to serve as intermediate measure, or term of comparison. This addition, which, by the effect of local circumstances, has become of absolute necessity, allowed us, besides, to verify, at the same time, one of the most useful physical laws, which had been extended to very high pressures, merely by induction. We speak of the relation between the volume of a gas, and the corresponding pressures, known by the name of the law of Mariotte.

It was therefore necessary to begin by graduating the manometre, that is, to measure the columns of mercury capable of making equilibrium to the different degrees of elasticity of the same mass of air reduced to volumes, successively decreasing, and differing only little in their successive terms.

Experiments requiring the direct measurement of a column of mercury, of 75 to 80 feet high, could not be executed every where; it became necessary to find a very high building, the interior distribution of which allowed to build the necessary scaffolding, to erect the column, and to observe it. We had first thought of attaching the tube to one of the exterior sides of the observatory, but the enormous expenses of the scaffolding, and the danger of having our instruments exposed to the injury of the open air, made us abandon this plan, particularly as we found a building which appeared to present more favorable localities.

In the buildings of the Royal College of Henry IV., is enclosed a square tower, only remnant of the ancient St. Genevieve. There existed still in the interior three arches pearced in their centre, which furnished more solid supports for the frame works. The College not having then made any use of this locality, we asked for its use from the provisor, and the direction of the civil buildings; and, after having fulfilled the required formalities, obtained the authorization to establish our apparatus in it.

In the middle of this tower was erected a vertical beam, well enough evened on one of its sides, and formed of three pieces of pine of 15 centimetres squaring, joined by double swallow tail, and fastened in a solid manner by iron bindings to the arches, and to the frame work, which formerly supported the bells. By these frequent bindings, all bending, which could have broken the glass column that was to be attached to it, was avoided. This glass column was composed of 13 glass tubes, of two meters each in length, five millimetres diameter, and the same thickness, made for us purposely in the glass-house of Choisi. Messieurs Thibeaudeau and Bontems, directors of that establishment, which is so useful to the arts by its proximity to the capital, have lent their assistance with a kindness which we cannot too much praise, to all the trials which we have been obliged to make, in order to obtain the quality of glass most suitable, and to render the tubes capable of a sufficient resistance; without, however, that they would, on account of their great thickness, break spontaneously by the variations in the temperature of the atmosphere. What was the most difficult in erecting such a high column, was the means to alleviate the lower tubes of the very great weight of the upper tubes, and the rings that unite them; which weight would have been by itself sufficient to crush them. We had at first intention to make every ring rest upon metal forks, fastened in the upright beam,

and to avoid the rupture of the tubes, which would have been occasioned by the unequal expansion of their matter, and their supports, by the use of compensation bars; we had even already calculated the co-efficients of the expansion of the substances that were to be opposed to each other, when we had the idea of another mean more simple, and which succeeded completely.

The glass tubes are united by rings, of which the vertical section is seen in fig. 1, plate 1. The upper ring rests, by a squared off surface, upon a piece of sole leather, which covered the bottom of the inferior ring. A screw of pression, which is pressed by means of a key, serves to join the surfaces of contact, so as to resist a very strong interior pressure. The elavated border, h, h, is intended to hold in the mastia, which is run upon the joint, if needed, to hinder the mercury from escaping sideways, and, at the same time, to fix in a horizontal position the small rule, k, adjusted upon its superior surface, which served as standard fixed point for the measurement of the heights, and which forms part of an independent piece, oo. The inferior tube, t, is kept in a collar, c, c, of iron, fig. 2 and 3, fixed to the side of the vertical beam by a foot and screws. By means of the screw, t, the ring is kept in a position almost invariable, by allowing to it only so much play as is absolutely necessary, that it may yield to the variations of temperature. The lateral shaking is thereby completely avoided; but, in order to unload the inferior tubes of all the weight of the superior tubes, there were placed above each joint two pullies, p, p, fig. 4, over which pass cords attached by one end to the screw, and at the other extremity bearing tin buckets, in which leaden shots were put, until their total load made equilibrium to each tube and its ring. By this disposition, which is represented in perspective in plate III, fig. 1, the inferior tubes were no more pressed than the superior ones; the whole column would move vertically, as one single piece, by the slightest effort. This rendered very easy all the manipulation required to unite it to the other parts of the apparatus. Plate 1, fig. 4, shows that the first ring was applied to a side arm of a vase, S, of soft cast iron, having three tubes of two centimetres thickness, and capable of containing 100 pounds mercury. Upon the orifice opposite to this, the manometer was placed, of which it will be necessary to give a detailed description, in order to appreciate the degree of exactitude of its indications.

The manometric tube, *a*, *a'*, of the same dimensions, in diameter and thickness, as those of the column, was only 1^m, 7 long. Before placing it, it was graduated with great care, but without making any stroke upon its exterior surface, because it had to bear very great pressures; two small pieces of laminated tin served as points of reference. After it had been hermetically sealed below, it had been strangulated near the other end, so as to leave only a very small passage of only glass, so thin, that it could be easily melted with the blow pipe. The tube being placed against a vertical board, at the side of a divided scale, furnished with a marking ring and a vernier, in the same position in which it was to be used in the experiments, a table was made of the lengths corresponding to a certain column of mercury, through the whole length of the tube. We pass over a multiplicity of details, that persons habituated to this kind of operations can easily imagine. We shall only say that this process had been adopted to avoid the pretty considerable errors that could have resulted, in high pressures, from the convexity of the mercury column, if the measure of the volume had not been made under the same circumstances as the graduation. This tube, cut off at the lower end, and having still at its superior part the narrow passage spoken of above,

was fastened by cement into the iron ring, bb', fig. 5, plate 1. To diminish the pressure which it would have to support in the experiments, the bottom of this ring offered an aperture only just equal to the column of liquid which was to be elevated in the tube. Without this arrangement, which avoided all the pressure exercised upon the annular surface of the glass, the cements could not have resisted, and the tube would have been torn out. The same precaution had also been taken for all the rings of the long column. Before putting it to its place, it had been well dried in the interior; but, for more security, a sufficient quantity of mercury was put in the cast iron vessel to elevate it in the tubes for two or three centimetres above the lower end of the tubes, and, by means of a pneumatic pump, a current of dry air was made to pass through the tube, for a considerable length of time, which was made to enter by the narrow channel still existing at the top, and which escaped through the metallic liquid. When it was presumed that no traces of dampness remained, the capillary part of the tube was melted by a sudden flame directed upon it with the blow pipe, at a certain point marked in graduating it, and the manometer was thus filled with dry air. This operation, executed with dexterity, can occasion no sensible error. It was, besides, made sure of, by verifying the graduation after having terminated the experiments.

In a plane passing through the axis of the manometric tube, were erected on each side, vertically, 2 brass rules; one of which was divided in millimetres, and had a vernier, to which a ring was attached for observing, in the manner used in the barometers of Fortin. These rules were joined at the top by a cross piece of brass, and fastened below to the plate of the ring.

The variations of the temperature of the air, which are communicated only after a considerable time to a mass of glass of several millimetres in thickness, would always have left a considerable uncertainty upon the temperature of the gas enclosed in the manometer, if it had been exposed to the open air. The only means to give to it, in all its parts, the same degree of heat, and a degree easily appreciable, was to place it in a mass of water continually agitated, that the different layers, at different heights, should not be unequally warm.

This was the aim of the glass covering tube, mm', which surrounded the tube and the rules. Water running continually from a superior reservoir, *e*, running rapidly down the whole length of the manometer, escaped below by a brass cork.

The liquid of the reservoir being, besides, of the temperature of the surrounding air, the mass of gas contained in the manometric tube, obtained of course in all its parts an equal temperature, which was determined by a thermometer X, suspended in the middle of the surrounding liquid. At *u*, *q*, *y*, is seen the necessary mechanism to direct the reading ring, and take the level in each observation. It consists in a silk cord, both ends of which are fast to the moveable piece, which passes over three superior, and one inferior pully, and which rolls round the winding axe, with a handle at the exterior, *u*, which it suffices to turn, in one way or the other, to bring the reading ring, and the vernier attached to it, higher or lower.

It appears from this description, that this mode of observing gives the same degree of accuracy as in the barometers of Fortin. To say that this able artist has constructed this apparatus, is giving the greatest guarantee for the perfection with which it has been constructed.

Lastly: the third tube, *n*, of the cast iron vase, could receive at will a

pump for liquid or for gas. We used first this latter, in order to avoid all dampness in the cast iron vase; but, after having discovered that the height of mercury contained in the reservoir was sufficient to hinder the water to pass in the manometer, we have substituted the water pumps, as much more expeditious.

We are now to proceed to describe the manner in which the observations were made, which were all made by Mr. Arago and myself. We began by determining the initial volume of the air in the manometer, and its elasticity at a given temperature. The volume was given by observing the point on the brass rule, to which the top of the mercury column corresponded, and by transferring these measures upon the table of graduation mentioned above. The elasticity was determined by the height of the barometer at the same moment, and the difference of level of the two columns of mercury in the great vertical column, and in the manometer itself. This difference was taken by means of the micrometer described in Annals of Chemistry and Physics, vol. VII., page 132.

The care taken to select the two tubes of the same diameter, dispensed with a full correction for capillarity. In putting into activity the one or the other pump, the volume of the air in the manometer was reduced at will, and the mercury was elevated in the vertical column, *d, d,* until equilibrium was established: it was, therefore, easy to determine terms, as near together as was desired. At each observation, the volume of air was determined, in the manner stated, to know the height of the column of mercury; the invariable difference of height between each two resting places of the lateral scale were previously determined by means of a divided rule, *g, g,* the rule point of which coincided exactly with the upper side of the inferior resting place, and the other end had a small complementary rule, which was pushed until it stood just even with the upper part of the next superior resting place, fig. 1, plate 1. The distances between each successive resting place were measured before hand, so that there remained at each observation only to mark the number of the tube in which the column of mercury ended, and to measure the difference of level between the summit of the column and the last resting place below, which was done by one rule adaptable to all stations equally, and which was furnished with a reading ring and a vernier.

To make these readings accurately, it was necessary to be enabled to place the eye always in the level of the summit of the column wherever this might be. The first establishment required, also, pretty delicate manipulations at the points of junction of the tubes. For this purpose, scaffolds were made at the distance of every two metres, with ladders of communication through the whole length of the vertical beam. Lastly: six thermometers were distributed upon the length of the column to ascertain the density of the mercury; and, in order to render their indications more coinciding with those of the adjoining part of the column, they were placed in pieces of tubes of the same dimensions with those of the column, and filled with mercury.

We made three series of experiments upon the same mass of air.

We shall only relate their results, all calculated and brought to the same temperature.

Table of the Elastic Force, and the corresponding volumes of the same mass of Atmospheric Air, the temperature being supposed constant during each observation.

Elasticity expressed in atmospheres of 0m 76 of mercury.	Elasticity expressed in centimetres of mercury.	Volume observed.	Volume calculated.	Temperature centigrade th.
1st series.				
1.	80,09	479,73	-	14,3
2.	156,9	244,687	244,88	14,3
4.	326,706	117,168	117,6	14,4
4,8	365,452	104,578	105,205	14,5
6,5	304,072	75,976	76,222	id.
7.	557,176	68,910	69,007	id.
9.	688,54	55,45	55,801	id.
11,6	883,94	43,359	43,466	id.
12.	933,346	40,974	41,137	id.
14.	1,070,862	35,767	35,881	id.
2d series.				
1.	79,497	481,806	-	13,3
2.	156,112	244,986	245,205	13,5
4.	313,686	121,542	121,989	13,6
4,7	362,11	104,795	105,488	12,5
5.	381,096	99,59	100,253	id.
6,1	464,752	81,787	82,218	12,6
6,6	508,07	74,773	75,208	id.
6,6	506,592	74,985	75,427	id.
7,6	578,162	65,723	66,09	id.
7,6	580,002	65,473	65,881	id.
8.	637,108	59,767	60,039	13,8
11,5	875,052	43,428	43,682	13,7
11,6	881,202	43,146	43,378	id.
12.	962,108	39,679	39,758	14,5
16,6	1,269,132	30,136	30,140	13,7
3d series.				
1.	76,	501,3	-	13
4,75	361,248	105,247	105,47	id.
4,94	375,718	101,216	101,412	id.
5.	381,228	99,692	99,946	id.
6.	462,518	82,286	82,380	id.
6,58	500,078	76,095	76,193	13
7,6	573,738	66,216	66,417	id.
11,3	859,624	44,308	44,325	id.
13.	999,236	37,851	38,132	id.
16,5	1,262,000	30,119	30,192	id.
17.	1,324,506	28,664	28,770	id.
19.	1,466,736	25,885	25,978	id.
21,7	1,653,49	22,969	23,044	id.
21,7	1,658,44	22,979	22,972	id.
24.	1,843,85	20,547	20,665	id.
26,5	2,023,666	18,833	18,872	id.
27.	2,049,868	18,525	18,588	id.

Besides the principal aim of the preceding experiments, they can also be used, as was said in the beginning, to determine whether the law of Mariotte may also be extended to pressions of 27 atmospheres.

Until of late years, it had been tried to verify this law only for pressions little superior to that of the common atmosphere. The trials of Boyle, (Defensio contra Linum T. V.) and of Muschenbroek, (Essay de Physique tome II., page 655,) appear to indicate that even under four atmospheres the compressibility of atmospheric air was diminishing for forces always increasing, so that to reduce a mass of air, at first submitted to the common pressure of the atmosphere, to a volume, for instance, four times less, there would be required a force more than four times greater than this pression, (Mariotte, Traite des Eaux, page 142, ed. in 12° of 1700. quotes no numbers, and indicates only the kind of apparatus by which the law can be verified, which he announces without restriction.) The experiments undertaken long after by Sulzer, (Memoirs of the Academy of Berlin, 1753,) and by Robison, (Encyclopedia Britannica, art. Pneumatics,) gave contrary results. The air reduced to $\frac{1}{8}$ of its original volume would possess an elasticity of only 6,8; the original elasticity being 1. But since our experiments have begun, Mr. Oersted has published those he made with Captain Suenson, (Edinburg Journal of Science, t. 4, p. 224; Bulletin Universel, t. 5, p. 331,) the elasticity of the air was measured till to eight atmospheres, by the length of a column of mercury to which it would make equilibrium, and the volumes were found pretty exactly in the inverse ratio of the corresponding pressures. These philosophers have even extended their observations till to 60. atmospheres, by determining this pressure by means of the weight necessary to overcome the resistance of a valve; but we do not think that entire confidence can be placed in this last mode of proceeding.

The preceding table presents the results of 39 experiments made upon the same mass of air, under pressures between 1 and 27 atmospheres. The third column presents the observed volumes, and the fourth the same initial volume multiplied by the inverse ratio of the corresponding elasticity; all corrections being made to bring the two terms to the same temperature.

The comparison of the third and fourth columns proves, that, in no case, the difference between the calculation and the observation exceeds $\frac{1}{100}$; that, in most cases, it is only about $\frac{1}{200}$, and, for some, nearly null. There is no indication that these differences augment with the pressures, as would be the case if they were caused by a real deviation of the law which it is intended to verify. Besides, according to the method usually employed to guage tubes, it must be expected that the observations be not all affected by the same error.

We have found that those terms that agree best with the calculation are just those which are the least distant from the points of graduation fixed by direct measurement; and for which, therefore, the supposition of an exact cylindrical form of the tube for a certain length has but a very slight influence.

It would have been easy to adapt to the manometer, an apparatus to measure the augmentation of capacity of the tube by the pressure from within; but, having found the whole length of the tube did not undergo any observable lengthening in comparison to the divisions of the scale which served to measure the volume, even when the pressure attained to its maximum, we concluded that the correction relating to this effect was not appreciable.

The law of the compression of the atmospheric air may, therefore, be considered as verified in a direct manner until 27 atmospheres; and it can

ithout doubt be applied much above this limit without any observable error. Though it was very probable that the other permanent gases should bey the same law, our intention was to submit, by the same apparatus, two r three other kinds of fluid to our observation, but we had at first to complete ie inquires called for by Government; and, when these were terminated, e could not obtain from the administration of civil buildings the further se of the building where our apparatus of compression was established. his circumstance is so much more to be regretted, as we would have been le to decide finally upon this important point of the mechanic of gases, ithout any augmentation of expense, and very little augmentation of the time; hile now it will require considerable expense, and several months of oublesome work, to take up again this subject where we left it.

Determination of the Force of Elasticity of Steam.

The experiments herebefore described could serve to indicate, by the vome of air in the manometer, the corresponding pressures not exceeding) atmospheres.

It was, therefore, sufficient to bring a boiler in communication with the anometer to measure the elasticity of the steam with the same accuracy as the column of mercury, making equilibrium to it, had been observed dictly. By operating in this manner, the advantage was gained to avoid e great oscillations of the metallic column. The apparatus had been so sposed that a boiler could be substituted for the pneumatic pump without ianging any other parts.

But having observed that the least explosion might occasion the fall of e three arches, the bad state of which made us even fearful of their sponieous fall, and fearful of the consequences of such an accident, which ight have endangered the neighboring buildings, we determined to make e experiments upon steam in one of the yards of the observatory. It beme, therefore, necessary to transport the manometer, without separating it om the cast iron reservoir to which it was joined, in order that the new dications of the instrument should be identical with the first. This transrtation was not without its difficulties on account of the enormous weight the whole together, and the great length of the air tube. However, with ultiplied precautions, we have succeeded in it, even so as to preserve in the be the same mass of air that was in it at first. This important point has en carefully verified.

A general idea of the apparatus may be obtained by plate III. figure 2, iere it is represented in perspective, and by plate II. fig. 1, which shows vertical section of it, in which the accessory parts are suppressed to avoid nfusion.

The boiler, a, plate II. figure 1, containing about 80 litres, was construct- in Charenton, under the direction of Mr. Wilson, whose knowledge and perience are well known to the Academy. It is formed of three pieces sheet iron of first quality, made expressly for this use, having 13 millietres in thickness in the cylindrical part, and much more at the bottom d near the opening. This opening has 17 centimetres in diameter, was ut by a plate of hammered iron 4,5 centimetre thickness, and 26 centimes diameter. This plate had on its lower part a circular rim well adjusted at e inferior part, which was received in a groove of the same form, made the thickness of the rim of the boiler, the bottom of which was lined with heet of lead. From the inside of the rim of the boiler were forcibly dri-

ven in six round steel bolts, with large heads, of 35 millimetres diamete passing upwards through the cover, the upper parts of which had screw and received a screw mother to be tightened by a key. In placing a ring lead between the screw mother and the cover, this metal entered by tl pressure in every interstices, so as to close hermetically even for the stron est pressure.

All this tight shutting required absolutely materials without defect, ar careful work. The cover alone had indeed to bear, in some experiment an effort from within equal to near 20,000 kilogrammes; and though tl dimensions were calculated upon the most unfavorable suppositions, it w prudent to try the boiler before putting it in use. This is what we fir tried to do by means of the water pump of the kind that are used for the h draulic presses. To apply to our boiler the article of the regulation rela ing to the preliminary trials, we would have been obliged to submit it to pression of 150 atmospheres; but, long before this term, some fissures in tl metal, and some riveted joints, oozed a quantity of water, equal to that whi the pump could inject in the same time, so that the pressure could no mo be increased. In making these trials, we have had occasion to observe what errors one can fall in estimating the pressure in the usual manner, t a conic valve laden with a weight that it shall lift. Independently of tl difficulty to know the extent of the surface exposed to the interior pressur the adhesion of the valve to the side surfaces of the cavity in which it is r ceived is very variable, and can occasion enormous differences under actu ly equal pressures. It would be preferable to apply flat valves, which, i deed, require constant care to keep in good order, or, still better, a con manometer, when the force of compression does not pass 50 or 60 atmo pheres. As it would have required a long time to adapt this mechanism our pump, and that, besides, the high temperature to which the boiler w to be exposed, would still have left us much uncertainty upon the dimin tion of the cohesion which might result from it in the metallic substances, v preferred submitting it to a more severe trial, by placing it in the very c cumstances of the experiment, and under the influence of an expansive for greater than that which was to form the subject of our observations. It principally for this trial that we invented the valve, which is represented b b, figure 1, plate II.; the construction of which furnished the advanta which could not be obtained by those used in common, to give free issue the steam as soon as its elasticity passes the term for which the two weigh have previously been calculated.

The moveable weights upon the two arms of the lever, are composed several pieces, capable of being united or separated; which allows to va their magnitude, according to the pressure which it is intended to reach, ar the least lifting of the valve causes them to slide—the one towards the ce tre of the motion, and the other towards the extremity of the opposite arr so as to let constantly the orifice open by which the steam can escape.

The cooling occasioned by the loss of steam through the joints, and by violent wind, together with some unfavorable dispositions of our furnac provisorily made in the foundries of Charenton, did not permit us to obser there the lifting of the valve, the load of which had been calculated for a elasticity of 60 atmospheres, but we had had the precaution to place a the mometer, the scale of which could be observed from a distance with a tel scope; and the temperature of 240°, to which the interior of the boiler w brought, led us to conclude, according to some results obtained in Englan that we were near to that term; therefore, we did not carry the trial farthe

It will be seen hereafter that, under these circumstances, the force of the steam had been but about half that to which we thought to have submitted our instrument.

This boiler, so tried, was established upon a furnace of a pretty considerable mass, that the whole system should not be subject to too sudden variations. An iron tube, *d d' d''*, composed of various musket barrels, was erected, first, perpendicularly upon the cover, and its lateral branch, *d' d''*, slightly inclined, was united at the end to the middle tube of the reservoir of cast iron, *f;* through this tube the pressure was communicated to the manometer. Before the experiment, this was first filled with water, and, in order to appreciate exactly the pressure exercised by this column, which was of course added to that of the steam, a small stream of water was constantly led upon rags, placed at V, near the superior bend of it. The interior of the apparatus being void of air, a constant light distillation was occasioned, which replaced the small portion of liquid, which the increase of elasticity of the vapor caused to drop in the cast iron vase, and that during the whole time of the experiment there was always resting upon the mercury a column of water, elevated to the junction of the inclined tube with the vertical tube *d*.

The variable lever *t t'*, of the mercury in the cast iron reservoir was known at every instant, by observing the column *k p*, communicating by its upper part with the same reservoir, by means of a leaden tube, O X; the elevation of the mercury above a certain fixed point, was taken by the scale *l m*, already described. Lastly, the elastic force of the steam was obtained by adding to the elasticity, corresponding to the volume of air in the manometer, the height of the mercurial column raised in this instrument above the level *t t'*, and subtracting the pressure due to the column of water contained between this same level and the fixed point, *d';* this quantity, which varied only for a few centimetres, had been determined in relation to a fixed point of the scale, *l m*, and the variable position of the summit K, served to find what was to be added to, or subtracted from, this element in each particular case.

There was some difficulty in measuring exactly the temperatures. The thermometer, whatever it might be, was not to be directly exposed to the pressure of the steam, for if even it could bear it without breaking, it would have been necessary to keep account of the effect of compression, which it would have been difficult to estimate. To obviate this inconvenience, two gun barrels were introduced, shut up at one end, and thinned so much as to leave only the resistance necessary not to be crushed during the experiment. The one reached nearly to the bottom of the boiler, the other did not reach to more than the quarter of its depth.

In the middle of these cylinders, filled with mercury, the thermometers were placed; the shorter one serving to give the temperature of the steam, the other longer one, that of the water, which preserved still its liquid state. This mean, the only one applicable in experiments of this nature, would be very defective without uniting to it the necessary circumstances to render the variations of temperature very slow. This is one of the reasons which lead us to give to our boiler, and to the furnace, greater dimensions than were rigorously necessary for our object; but we have ascertained repeatedly, that, near the maximum, the slightest variations of elasticity of the steam, either increasing or decreasing, were accompanied by corresponding variations in the thermometers.

If we had only immersed these instruments in the reservoirs just mention-

ed, the corrections arising from the temperature of the part of the tubes outreaching, which is always much lower, would have been uncertain; this care might indeed have been dispensed with, by using thermometers with weights; but, as the observations were to be very numerous, we preferred to preserve to the instrument its usual form, by giving to the whole tube an uniform temperature easily determinable.

Fig. 2, plate II, shows that this tube was bent at right angle over the cover of the boiler, and was enclosed in a glass tube, in which water was let from a great reservoir. The temperature of this liquid, which varied very slowly, was communicated to the stem, and was shown by a smaller thermometer laid horizontally at the side of it. Thus was read off at each observation, after the principal indication of each thermometer, the temperature of the mercury of each stem, and, by a very easy calculation, the same precision could be obtained as if the whole thermometer had been immersed in the boiler. It is useless almost to say that these instruments had been well calculated, and that they presented in their graduation all the precision which can now be given to them.

After this description of the apparatus, it is easy to imagine the manner of operating; the boiler being charged with a convenient quantity of water, so that the reservoir of the small thermometer was entirely above its surface, the liquid was put in ebullition for fifteen or twenty minutes; the safety-valve being opened, and also the extremity *d'*, of the vertical tube, to let out completely the remainder of the atmospheric air, and the gases that were disengaged; all the issues were stopped, and the brass cocks that let in and out the water in the tubes in which the manometer and the thermometers were, and for the condensation of the steam at V, in the iron tube. The furnace was previously supplied with a quantity of combustible, greater or less, according to the temperature, more or less high, which it was intended to attain. Then the moment was waited for when the ascending of the degree of temperature became less rapid; one of us observed the manometer, and the other the thermometers, and when the gradual elevation of temperature became very slow, we began to write down the simultaneous indications of the manometer, of the four thermometers of the boiler, and the elevation of the mercury in the lateral tube *op*. We thus took several numbers very near each other, until we had attained the maximum; only the observation made at that term was calculated; the previous and the following served only to secure against errors of reading. When the manometer and the thermometers had sensibly fallen, combustibles were again added, and we proceeded again in the same manner. We could, of course, by this means not obtain the elastic force corresponding to a previously determined temperature; but, by making many observations, we obtained a sufficient number of terms, near enough to each other, upon the whole length of the scale. We had the intention to extend the experiments till to thirty atmospheres, but the boiler lost such a great quantity of water, that we could not go above twenty-four. It will soon be seen that it would be allowable to supply by calculation for the direct observations, even for pressures far more distant from the limits at which we have been obliged to stop.

The explanations hitherto given show enough how the observations were to be calculated. As all the scales were arbitrary, these calculations required much time. It would be useless to quote here all the intermediate calculations: we will give only the ultimate results. The comparison of the terms near each other has served for verification.

	No. of the observation.		Small thermometer.	Large thermometer.	Elastic force in metres of mercury.	Elastic force in atmosphere of 0m, 76.	Particular state of the observations.	Elastic force in metres of mercury at 0°.
1	29th Oct.	3	122,97	123,7	1,62916	2,14	maximum	1,62916
2	25th Oct.	1	132,58	132,82	2,1823	2,87	asc. temp.	2,1757
3	28th Oct.	1	132,64	133,3	2,18726	2,88	near maxim.	2,1816
4	28th Oct.	2	137,70	138,3	2,54456	3,384	asc. temp.	2,5386
5	29th Oct.	5	149,54	149,7	3,484	4,584	maximum	3,4759
6	28th Oct.	3	151,87	151,9	3,69536	4,86	asc. temp.	3,6868
7	25th Oct.	2	153,64	153,7	3,8905	5,12	asc. temp.	3,881
8	2d Nov.	1	163,00	163,4	4,9489	6,51	maximum	4,9383
9	30th Oct.	4	168,40	168,5	5,61754	7,391	maximum	5,6054
10	28th Oct.	4	169,57	169,4	5,78624	7,613	asc. t. slow	5,7737
11	23d Oct.	3	171,88	172,34	6,167	8,114	asc. temp.	6,151
12	28th Oct.	5	180,71	180,7	7,51874	9,893	near max.	7,5001
13	25th Oct.	4	183,70	183,7	8,0562	10,6	asc. temp.	8,0352
14	28th Oct.	6	186,80	187,1	8,72218	11,48	asc. t. slow	8,6995
15	22d Oct.	2	188,30	188,5	8,8631	11,66	maximum	8,840
16	25th Oct.	5	193,70	193,7	10,0254	13,19	asc. temp.	9,9989
17	28th Oct.	7	198,55	198,5	11,047	14,53	asc. t. slow	11,019
18	25th Oct.	6	202,00	201,75	11,8929	15,63	asc. temp.	11,862
19	24th Oct.	1	203,40	204,17	12,321	16,21	asc. t. slow	12,2903
20	25th Oct.	7	206,17	206,10	13,0211	17,13	asc. temp.	12,9872
21	2d Nov.	6	206,40	206,8	13,0955	17,23	maximum	13,061
22	24th Oct.	2	207,09	207,4	13,167	17,3	near max.	13,1276
23	28th Oct.	8	208,45	208,9	13,7204	18,05	asc. temp.	13,6843
24	25th Oct.	8	209,10	209,13	13,8049	18,16	asc. temp.	13,769
25	25th Oct.	9	210,47	210,5	14,1001	18,55	near max.	14,0634
26	28th Oct.	9	215,07	215,3	15,5407	20,44	asc. temp.	15,4995
27	28th Oct.	10	217,23	217,5	16,1948	21,31	asc. temp.	16,1528
28	28th Oct.	11	218,3	218,4	16,4226	21,6	near max.	16,3816
29	30th Oct.	8	220,4	220,8	17,2248	22,66	asc. temp.	17,1826
30	30th Oct.	1	223,88	224,15	18,2343	23,994	maximum.	18,1894

The preceding table contains the thirty observations made under the most favorable circumstances.

The two thermometers agree as exactly as may be expected in observations of this nature. The greatest deviation is only 0°, 7, and this is only in the lower part of the scale, which is probably due to the special situation of the apparatus. Supposing that the maximum of temperature was rigorously the same in the steam and in the water, the two thermometers should not have indicated exactly the same degree: the reservoir of the smaller, surmounted by a column of mercury much shorter, and immersed in a medium of which the slight density retarded the communication of the heat, was necessarily more under the influence of the cooling, occasioned near the cover of the boiler. This cause was weakened as the temperature was elevated, because the quantity of heat which the steam could give off, in the same time, to the envelope of the thermometer, increased about in the same ratio as its density: therefore, also the differences of the readings diminish in proportion

as the tensions become stronger. This applies to the observations in which a maximum took place. In those made during an ascending motion of the temperature, the two instruments agree much better; but the cause of it is, that the great thermometer surrounded by a much longer column of mercury, required more time than the other to come to an equilibrium, and that, at the same moment, it was naturally more distant from the temperature of the surrounding medium than the smaller one.

Upon these considerations, we consider as more exact the numbers furnished by the thermometer immersed in the water, in all observations made at the maximum of temperature.

That we might not have to fear that the steam was really at a lower temperature than the water, we took care besides to ascertain, as we have already said, that the manometer indicated a diminution of tension at the same moment when the great thermometer began to retrograde; which proves that the space was saturated with steam for the temperature indicated by the instrument.

We have constructed the curve of these observations: it presents a perfect regularity. Choosing any two terms, even very near together, it never occurred that an observation, intermediate between them, fell on the other side of the cord which united the two extremes.

A number of experimental researches had already been undertaken upon the same subject, but they extended mostly only to pressions of four or five atmospheres; only a few went as far as eight.

In examining attentively the methods used, where they have been carefully described, it is easy to find in it the probable causes of the differences which they present, compared with ours.

Only the observations of Southern and Taylor show a coincidence with these, which is so much more striking, as they were furnished by a mode of observing entirely different from ours. Already, at the time when we calculated the table inserted in the provisory support, quoted above, we considered them as the most probable; therefore, also, the differences between that table, and the one which we are going to give, are nearly insignificant in the part which they have common.

Above eight atmospheres we knew but one single number, which Mr. Perkins had communicated to Mr. Clement. According to this celebrated engineer, the force of the steam at the temperature of 215° cent. would be of 35 atmospheres, while we found it only of 20. Having no information upon his mode of observing, we cannot comprehend how the author could make a mistake of 15 atmospheres upon the elasticity, or of 30° upon the temperature; for the multiplicity and regularity of our results will not allow us to suppose the error on our side.

Only since a short time we have found in a German book, very little known in France, the Annuary of the Polytechnic Institute of Vienna, a series of observations made with great care by Arzberger, professor of that institution, (Johabucher Desk, *k*, Polyt. Inst., t. 1, page 144. 1819, Polytechnishez Journal Von Dingler, t. 12, p. 17, Bulletin des Sciences Technologiques, t. 1, p. 123.) Here again the elasticity of the steam is still measured by the effort necessary to oppose to the opening of a valve with a lever. Though this mode of proceeding is always inferior, in point of accuracy, to that which we have employed, we may presume that the errors upon the resulting elasticity must have been much diminished by the precaution taken to use a spheric valve of steel, resting upon a ring of a circular

rifice in another piece, made of the same metal, and by the perfection of he work of all the other pieces of the machinery; but the estimate f the temperature appears to have always been carried too high. The nvelope of the thermometer, which was immersed immediately in the waer, having been subject to all the internal pressure, must necessarily have een subject to a diminution of capacity, and caused the temperatures to be steemed higher than they actually were. This error, the extent of which ve could not justly estimate, and which would vary with the thickness of ach envelope, would undoubtedly have been much greater, even if another irectly contrary one had not, at the same time, been occasioned. The tube f the same instrument, placed horizontally outside of the boiler, could not articipate in the heating of the reservoirs, and the author does not indiate any correction relating to this circumstance. It is therefore very proable that the greatest elasticity observed by Arzberger, was really of about 20 atmospheres; but he indicates for this tension a temperature of 222°, which corresponds with us to 23 atmospheres. All other terms are affected by a similar error from the same cause, but smaller in proportion as the tensions decrease.

The physical law, which would express exactly the force of elasticity of steam in a function of the temperature, is no more evident by our observations than by those which we possessed before in the lower parts of the thermometric scale. It will be discovered, probably, only upon theoretical considerations, and when we shall know the density corresponding to these different degrees of elasticity. In the mean time, we may try a formula of interpolation, adapted to show the elastic force for any point of the thermometric scale.

We shall here consider some of those that have been proposed until this day.

The most of them have been applied only to pressures belonging to a small number of atmospheres, and though they may have presented within this interval an approximation sufficient for the ordinary use, it is not astonishing that they will no more agree beyond these limits.

The first formula is that of Mr. De Prony, which was made to represent the observations of Betancourt. The length of the calculations necessary to determine the six constant quantities which enter in this formula, and even to make use of them when they are known, has caused this method of interpolation to be abandoned. (This formula is $z = \mu_{\prime}\rho_{\prime}^{x} + \mu_{\prime\prime}\rho_{\prime\prime}^{x} + \mu_{\prime\prime\prime}\rho_{\prime\prime\prime}^{x}$; where z is the force of elasticity of the steam, and x the temperature, Archit. Hydr. t. 2, p. 192.)

Mr. La Place, (Mecanique Celéste, t. 4, p. 233,) grounding upon the approximative law announced by Dalton, namely: that the elastic force of steam increases nearly in geometric progression for temperatures in arithmetic progression, represents the elastic force by an exponential quantity, of which the exponent would be developed in a parabolic series. The two first terms appeared to him sufficient, but Mr. Biot proved the necessity to take a third, (Traité de Phisique, t. 1, page 277 and 350.) But using this kind of expression outside of the limits of the data that have served to determine the value of the indetermined co-efficients, they prove to deviate the most from observations. To comprehend in the same formula the whole of the observations hitherto made, it would be necessary to take five or six terms of the series, which would render the calculation interminable. We think this method must be entirely abandoned; the formula of Mr. Ivery being of the same nature, though its co-efficients have been calculated by another

process, would present the same inconveniences. At the high temperatu of our experiments, it would give an elastic force more than double of tl which was observed, (Philos. Magazine, new series, vol. 1, page 1.)

Dr. Ure has proposed a method of easy application, and which agrees w enough with experience, as long as it is not extended over five or six atm pheres. He has observed that, from 210° Fahrenheit, where the elas force is 28 in. 9, (English measure) for an elevation of 10° of the same sca the new elastic force is obtained by multiplying the preceding by 1, 23, a for 10° higher in multiplying with 1, 22, and so on, diminishing always t factor for one unit in the last order of the figures for every increase of 10 Besides, that this rule would not solve the inverse question, it is evide that, at the temperature of 440° Fahr., which is about the highest limit our observations, an augmentation of 10° would give no increase of expa sive force; and that, for temperatures a little above, the elastic force wou diminish, which is absurd.

Mr. Roche, professor of mathematics at the school of marine artillery Toulon, has sent to the Academy, in the beginning of last year, a mem upon the law of the elastic force of steam. The author proposes himse not only to establish an interpolation for the use of the arts: he considers t formula at which he arrives as a physical law, deduced, by calculation, fro the most general principles of the theory of steam.

It would be too long to enter here upon the details of the reasoning up which Mr. Roche grounds: we do not think that they will obtain the asse of the philosophers. We acknowledge, however, that the formula at whi he arrives is one of those that agrees the best with the observations. (Th formula is $F = 760 \times 10^{\frac{m x}{1+0,03 x}}$ where F expresses the force of steam millimetres of mercury, and x the temperature in centigrades, to go off fro 100° positive for above, and negative for below. The mean valve of m, d duced from our observations, would be $m = 0,1644$.) This agreeme would however be very imperfect, if the co-efficient deduced from the o servations below 100° were used; but, calculating upon the preceding dat and taking the mean of the values referring to 7, observations, chosen in th interval from one to twenty-four atmospheres, the formula is in error onl for one degree in 24 atmospheres, and for one-tenth only near two atmo pheres.

About at the same time, Mr. Auguste, of Berlin, published a formul (Annalen der Physic und Chemie., 1828, t. 5, pag. 128, and Bulletin Un versel, tom. 10, pag. 302,) which has that in common with the preceding- that the elastic force is represented in it by an exponential quantity, the ex ponent of which is a fraction, having the temperature as factor in the nu merator, and in the denominator, (this formula is $e = a\left(\frac{b}{a}\right)^{\frac{(w+n)t}{n(w+t)}}$ where is the elasticity in metres of mercury, a, the elasticity of the steam at 0 $b = 0, 76$; $n = 100$; $w = 266\frac{2}{3}$, and t the centigrade temperature from th melting ice, and reduced to numbers log. e, $= \frac{23,945371.t}{800+3,t} - 2,296038$ But the author makes use of entirely different considerations to establish it and, besides, the temperatures are not taken upon the mercury thermometer— they are supposed reduced to the air thermometer. We have calculated th temperature which, according to this formula, would correspond to a tensior

of 24 atmospheres; it is found = 214°,37, the observation gives = 224°,2 upon the mercury thermometer, which would be reduced only to 220°,3 upon the air thermometer. The difference is therefore about 6°, or, if we require the elasticity for the temperature of 220°,2 of the air thermometer we would find an excess of more than two metres of mercury.

We find yet in the 19th No. of the Edinburg Journal of Science, pag. 68, another formula, proposed by Mr. Tregaskis, who thinks, having verified by the ancient observations, that the elastic forces increase in a geometric progression, the ratio of which is 2, when the temperatures increase also in a geometric progression, the ratio of which is 1, 2. This formula does not agree with the observations made at high temperatures; this comes to suppose that the elasticity increases as a certain power of the temperature. To ascertain whether such was actually the law of the phenomenon, we have determined the exponent of this power upon the most elevated terms of the preceding table, which, according to all appearance, has the smallest error. The formula thus obtained has then been applied to the other terms. The deviations of 2, which then appeared, show that the variations of the force of steam cannot be represented by the union of two geometric progressions.

Almost all the other formula hitherto proposed rest upon the same idea, and differ only in the constant quantities employed. Mr. Young appears to be the first who made use of that mode of interpolation, which consists in representing the elastic force of steam by a certain power of the temperature augmented by a constant number. Mr. Young had found that the exponent 7, satisfied to the experiments known at the time of the publication of his work, (Nat. Philos., t. 2, p. 400.) Creighton took the exponent 6, which appeared to him better to agree with the results of Dr. Ure, (Philos. Magazine, t. 53, p. 266.) Mr. Southern adopted the number 5, 13, which he determined evidently by trial, (tatonement) (Robinson Mecan. Philosophy, t. 2, p. 172.) Mr. Tredgold took again the exponent of Creighton, changing the co-efficient (Treatise on Steam Engines, 1828, 4° translation of Mellet, p. 101.) Lastly, Mr. Coriolis, in his interesting work just published, (on the calculation of the effect of machines, 1829, in 4° p. 58,) the formula is $e = \left(\frac{1+0,01878.\ t}{2,878}\right)^{5,355}$; where e expresses the elasticity in atmospheres of $0,^{m}76$, and t, the temperature, in centigrade degrees starting from 0°, adopts the exponent 5,355 deduced from the observations of Dalton below 100°, and from the table which we have given in our preliminary report to the Government, (Annales de Chimie et Physique, t. 27, p. 101.) This formula differs very little from that which we made use off, then, to calculate the table just mentioned. It satisfies very well to the extremes of observation, and deviates only for two or three tenths of a degree from the intermediate numbers. But we prefer the formula $e = (1+0,7153\ t)^5$ as of more easy use, and still more perfect, representing by e, the elasticity in atmospheres of $0,^{m}76$, and by t, the temperature to start from 100°, positive above, and negative below, taking as unity the interval of 100°. The only co-efficient which enters in this expression has been deduced from the most elevated term of our observations.

We have united in a table the values which would be given for the principal terms of the series by the four formula which deviate the least from experience, and are not of too laborious calculation.

These formula are,

1. Of Tredgold; $t = 85\sqrt[6]{f} - 75$; t being the temperature centigrade from 0°, f, the elasticity in centimetres of mercury.

2. Of Roche; $t = \frac{11\,(\log. f - \log. 760)}{0{,}1644 - 0{,}03\,(\log. f - \log. 760)}$; t = temperature centigrade above 100°, f = elasticity in millimetres of mercury.

3. Of Coriolis; $t = \frac{2{,}878\sqrt[5{,}355]{f} - 1}{0{,}01878}$; t = temperature centigrade from 0°, and f = elasticity in atmospheres of 0,m 76.

4. By our adopted formula; $t = \frac{\sqrt[5]{f} - 1}{0{,}7153}$; t = temperature centigrade from 100°, the unit used being = 100°, and f = elasticity expressed in atmospheres of 0,m 76.

No. of observation.	Elasticity in metres of mercury at 0°.	Elasticity in amospheres of 0,m 76.	Observed temperature.	Temperature calculated by the formula. Of Tredgold.	Of Roache, (mean co-efficient.)	Of Coriolis.	Temperature calculated by the adopted formula.
°			°	°	°	°	°
1	1,62916	2,14	123,7	123,54	123,58	123,45	122,97
3	2,1816	2,8705	133,3	133,54	133,43	133,34	132,9
5	3,4759	4,5735	149,7	150,39	150,23	150,3	149,77
8	4,9383	6,4977	163,4	164,06	163,9	164,1	163,47
9	5,6054	7,3755	168,5	169,07	169,09	169,3	168,7
15	8,840	11,632	188,5	188,44	188,63	189,2	188,6
21	13,061	17,185	206,8	206,15	207,04	207,43	207,2
22	13,137	17,285	207,4	206,3	206,94	207,68	207,5
25	14,0634	18,504	210,5	209,55	210,3	211,06	210,8
28	16,3816	21,555	218,4	216,29	218,01	218,66	218,5
30	18,1894	23,934	224,15	222,09	233,4	224,0	224,02

The comparison of the five last columns of this table, shows, that, unt three or four atmospheres, the three first columns represent pretty faithfu ly the observations; but from there, the fourth formula, which is that whic we have adopted, is always nearer to the results of the observations. Th greatest difference is 0,°4; almost all the others are only 0°,1. The great deviation, which is seen in the two first terms, would be of little consequen in that part of the scale. Though, by the nature of the experimental pr cess which we have employed, the errors must be proportionally grea er for the low pressures, it is not probable that the formula should be error from this cause, for it is observable, that, for pressures smaller than a atmosphere, the divergency augments more and more in descending lowe It appears, therefore, that the use of the formula must be limited to tensio superior to one atmosphere. That of Tredgold may be used till to 100 and even till to 140°.

Having thus found a very simple formula, that agrees so perfectly wi experience, it may be used to construct the table, which is the princip object of these researches; and, as the only co-efficient which occurs in has been determined by means of the last term of the series, it cannot be doub ed, on seeing the coincidence with the preceding terms, that it may exte

much above, without sensible error. We are sure that at 50 atmospheres, the error would not be of one degree.

The following table contains the temperatures calculated for pressures, increasing, by half atmospheres, from 1 to 8; and by whole atmospheres, from 8 to 24, where the observations stop; and, lastly, by 5 atmospheres, from 25 to 50, supposing the formula to extend till there.

TABLES of the Elastic Forces of Steam, and their corresponding temperatures, from 1 to 24 atmospheres, according to observations; and from 24 to 50, according to calculation.

Elasticity of steam, the atmosphere being unity.	Column of mercury at 0°, measuring the elasticity.	Corresponding temperature of the centigrade thermometer of mercury.	Pression upon one centimetre square.
1	0,7600	100,°	1,033
1½	1,1400	112,2	1,549
2	1,5200	121,4	2,066
2½	1,9000	128,8	2,582
3	2,280	135,1	3,099
3½	2,66	140,6	3,615
4	3,04	145,4	4,132
4½	3,42	149,06	4,648
5	3,80	153,08	5,165
5½	4,18	156,8	5,681
6	4,56	160,2	6,198
6½	4,94	163,48	6,714
7	5,32	166,5	7,231
7½	5,70	169,37	7,747
8	6,08	172,1	8,264
9	6,84	177,1	9,297
10	7,60	181,6	10,33
11	8,36	186,03	11,363
12	9,12	190,0	12,396
13	9,88	193,7	13,429
14	10,64	197,19	14,462
15	11,40	200,48	15,495
16	12,16	203,60	16,528
17	12,92	206,57	17,561
18	13,68	209,4	18,594
19	14,44	212,1	19,627
20	15,20	214,7	20,660
21	15,96	217,2	21,693
22	16,72	219,6	22,726
23	17,48	221,9	23,759
24	18,24	224,2	24,792
25	19,00	226,3	25,825
30	22,80	236,2	30,990
35	26,60	244,85	36,155
40	30,40	252,55	41,320
45	34,20	259,52	46,485
50	38,00	265,89	51,650

The temperatures corresponding to tensions, from 1 to 4 atmospheres, have been calculated by the formula of Tredgold; which, in this part of the scale, agrees better with our observations than the other.

The Academy will see that, from the experiments made by Mr. Arago and myself, result, 1. The verification of the law of Mariotte, till to 27 atmospheres; 2. A table of corresponding temperatures and tensions of the steam, not exceeding 24 atmospheres. This table is what the administration wished for the execution of the ordinance previously quoted.

These researches, always laborious and often dangerous, would have required several years assiduous work. The interruption which other duties, and circumstances independent of our will, have forced upon us, have prolonged their duration. This delay could not, without injustice, be attributed to any neglect on our part. Persons habituated to the great experiments of natural philosophy, can alone appreciate the magnitude of the task imposed upon us, to which nothing comparable would be found in our archives, and which required, on our part, a devotedness which the Academy would perhaps not have had the right to expect from every one of its members. We shall not regret the time which we have given to it, if the Academy judges that we have properly executed the commission entrusted to us, and if, at the same time, that we answered the wishes of the Government. The results which we present are considered by the philosophers an acquisition to the science.

The committee having taken cognizance of this work, has the honor to propose to the Academy to address to H. E., the Minister of the Interior, the present report upon the researches undertaken at their request.

Made at the Institute, the 30th November, 1829.

Baron de PRONY,
ARAGO,
GIRARD,
DULONG, *Rapporter.*

*TABLE of French Measures.**

		Eng. inch. Dec.
A millimeter is the 1000th part of a meter	-	03937
A centimeter is the 100th part of a meter	-	39371
A decimeter is the 10th part of a meter	-	3.93710
A meter - - - -	-	39.37100
	— $39^{m},3810 \times 22708$	32° of Fahrenheit.
A decameter 10 meters -	-	393.71000
A hecatometer 100 meters -	-	3937.10000
A chiliometer† 1,000 meters -	-	39371.00000
A myriometer 10,000 meters -	-	393710.00000
A grade or degree of the meridian equal to 100,000 meters, or 1.100th part of the quadrant - - - -		3937100.00000

The meter thus being, in English inches, 39.371, or 3 feet 3 inches and 371 decimals,

	Ms.	Fur.	Yds.	Ft.	In.	Dec.
The decameter is - - -	0	0	10	2	9	7
The hecatometer - - -	0	0	109	1	1	
The chiliometer - - - -	0	4	213	1	10	2
The myriometer - - -	6	1	156	0	6	
The grade or decimal degree of the meridian	62	1	23	2	8	

* The new French denominations are reduced to English orthography and accentuation.

†Ch have the sound of k.

Manometer, rare, and measure—An instrument to measure or show the alterations in the rarity or density of the air.

Vernier—A graduated index, which subdivides the smallest divisions on a straight or circular scale.

No. 30.

By Dr. Ure, of Glasgow.—According to the elaborate experiments of this gentleman, the elastic force of the vapor of water at 212° is equivalent to the pressure of a column of mercury 30 inches high, or equal to about 15 pounds avoirdupois on a square inch.

At temp.	212°	30 inches mercury	15 pounds sq. inch.
	226.3	40	20
	238.5	50.3	25.15
	248.0	60	30
	257.5	69.8	34.9
	273.7	91.2	45.6
	285.2	112.2	56.1
	312.0	166	83.0

Mr. Woolf has ascertained that, at these temperatures, omitting the last, a cubic foot of steam will expand to about 5, 10, 20, 30, and 40 times its volume respectively; its elastic force, when thus dilated, being in each case equal to the ordinary pressure of the atmosphere, provided that the cylinder in which the expansion takes place have the same temperature as the steam possessed before it began to increase.

High Pressure Principle.

The most economical mode of employing this principle consists in the application of two cylinders and pistons of unequal size to a high pressure boiler, the smaller of which should have a communication, both at its top and bottom, with the steam vessel, a communication being also formed between the top of the smaller cylinder and the bottom of the larger cylinder, and vice versa. When the engine is set to work, steam of a high temperature is admitted from the boiler, to act by its elastic force on one side of the smaller piston, while the steam which had last moved it has a communication with the larger or condensing cylinder. If both pistons be placed at the tops of their respective cylinders, and steam of a pressure equal to 40 pounds on the square inch be admitted, the smaller piston will be pressed down, while the steam below it, instead of being allowed to escape into the atmosphere, or pass into the condensing vessel, as in the common engine, is made to enter the larger cylinder above its piston, which will make its downward stroke at the same time as that in the smaller cylinder; and, during this process, the steam which last filled the larger cylinder will be passing into the condenser to form a vacuum during the downward stroke.

To perform the upward stroke it is merely necessary to reverse the action of the respective cylinders, and it will be effected by the pressure of the steam in the top of the small cylinder acting beneath the piston in the great cylinder; thus alternately admitting the steam to the different sides of the smaller piston, while the steam last admitted into the smaller cylinder passes regularly to the different sides of the larger piston, the communication between the condenser and steam boiler being reversed at each stroke.

The principle of the *high pressure* steam engine depends also on the power of steam to expand itself very considerably beyond its original bulk, by the addition of a given quantity of caloric, thus acquiring a considerable elastic force (equivalent to from 40 to 60 lbs. on each square inch,) which, in this case, is employed to give motion to a piston. * * * * *

The process of condensation forms no part of the principle of the "high-pressure" engine. * * * *

A quantity of steam having the force of five, six, seven, or more pounds on every square inch of the boiler, may be allowed to expand itself to an equal number of times its own volume, when it would still have a pressure equal to that of the atmosphere, provided the cylinder in which the expansion takes place has the same temperature as the steam possessed before it began to increase. [*Gregory's Mathematics, page* 346, *&c.*]

No. 31.

Extract from the 5th Report of the Select Committee on Steamboats, &c

HOUSE OF COMMONS, *June* 12, 1822.

Beside the precaution of having a sufficient number of boats to secure the safety of the passengers in case of any sudden accident, there ought to be on board every steamboat, for the perusal of the passengers, a certificate of some experienced engineer, to testify the strength of the boilers, the sufficiency of the valves, the safety of the furnaces, and the general good condition of the vessel and machinery.

Mr. Timothy Bramah, Mr. Donkin, and Mr. Field, say that the engine should be made so strong that it may be brought to rest without the fracture of any of its parts, in case it met with a resistance that would require its ultimate power. They mention instances that have come under their own personal observation, of engines having, in this way, stopped with no other effect than that of the steam forcing open the safety-valve and going off.

It may be collected from the evidence, that the greater part of the breakages which have occurred of different parts of the machinery in steamboats, has been owing to the negligence of the engine keepers: starting the engine without clearing off the water which is formed on the top of the piston, from condensed steam, is one cause of fractures. Other accidents have arisen from suffering the bearings upon which the shafts work, and the links connecting the piston with the beam, to get loose, and, in some cases, from making them so tight that the bearings heat; and also from not attending carefully to the steam valve when the vessel is exposed to a heavy sea. Mr. Watt says that much must always depend upon the vigilance and experience of the men who work the engines.

Mr. James Brown, being asked what were the causes of accidents to the machinery, replied, "they depended more on the engine keepers than any thing else."

Mr. Donkin says: "I have reason to believe that some of the steamboat companies have suffered severely from a want of regular professional inspection." And being asked, "Do you conceive the injury to engines from neglect is greater than the injury arising from the actual working of them?" replied, "Yes, I do."

Mr. T. Bramah says: "You cannot have too much power; indeed it is always of advantage to have as much power as can be obtained."

Messrs. Maudsley & Field say: "Two engines of half the power each are more manageable, and possess many advantages over one of the whole power; they produce a perfectly uniform rotation in the wheels, and are not subject, like single engines, to be stopped on the centre in heavy seas; and, in case of injury to one engine, the other is available."

Mr. Galloway and Mr. Perkins feel confident that high-pressure boilers may be so contrived as to be used with the greatest advantage. Mr. Perkins says they are used in 150 steamboats in America.

Your committee are of opinion that every part of an engine for a Holyhead steamboat should be made of wrought iron, except where there is no risk of breaking, and should be effectually proved before using it, by a proper proving machine; that the boilers should be made of copper; and that the air pump, buckets, rods, and valves, should be made of copper or brass.

Examination of Geo. H. Freeling, Esq. agent for the Holyhead Steam Packets.

Under whose care are the engines? Under the charge of the engineers. When the packets were first established, as it was at so great a distance from London, we wanted men, not merely practical engineers, but having a greater portion of science than men of that description generally have: we were obliged to give very high wages, but we got certainly the two best men there were; we were obliged to buy them out of their situations in the river, one for each of the two vessels, the Meteor and the Sovereign.

Each engineer has charge of his own engine? Yes.

In what manner is the packet commanded? There are four captains, who take it in turn. There being three vessels, (including the Ivanhoe) each has charge of the vessel going the six days in turn, and once in a month the captains go off duty for eight days; the fourth allows a relief.

There have been some accidents to the engines? Yes, there have; but I hope that will be prevented in future. It was, I think, I may say almost certainly, to be attributed to the use of cast iron: the cross-bars and the beams were of cast iron, and if any water was in the cylinder at starting, the check caused the cast iron to break; we have now got them made of wrought iron, but the lower beams of the engines, (two engines of 40 horse power each) which are very large, are still of cast iron; there must be some part of the engine left to give way, which is better than destroying the cylinder. We have now got solid shafts of malleable iron.

Examination of Capt. Wm. Rogers.

Do you find that sails assist considerably in the speed of the vessel? I have found the Sovereign go as fast in a calm as at any other time. It must not be thought that a steamboat running before the wind in a gale and a heavy sea, that she ought to make the quickest passage, as we are then obliged to shut off half the steam, or a great part of it: for, should you allow the full power to be on, the wheels running two or three times round without touching any thing between the trough of the sea and their being brought up all at once, something will probably give way. By moderating the steam, the engine goes as easy as a glove.

Has the great weight of the timbers and materials diminished their speed? No, I think it rather gives them speed against a sea.

Are the committee to understand your opinion to be, that, in any weather, however severe, the steamboats will stand that weather as well as any sail boat?

Yes, in any wind; the more wind the better for the steamboats; that is, where they show their superiority.

In building a steamboat she ought to have a fine entrance, and her bow to flear off, not to shove any water before her; any water she shoves before her must be an impediment to the sailing. She should have a fine entrance, a good line of bearing, and her transom pretty square, and not too high; the more you can stop a vessel from pitching and rolling the quicker she will go. In a high sea, the Scotch boats go, with a head sea, with the stern under, boat and every thing under. The transom being square and low, and fine under, so as to give them a right line of bearing, will stop their pitching and rolling, and make them easy on the sea, and add to their speed.

Mr. James Brown, agent for Boulton & Watt.—Room should be left entirely round the boilers; they could then be painted every month, which would be a great advantage, for the action of salt water is very detrimental to the iron; they ought to be painted every three weeks or every month. Where a boiler will not leak with fresh water, it will with salt water, and it forms incrustation upon the surface by exposure to the atmosphere. They should be pumped out, and frequently cleaned.

The engineer should look over his engine every morning before he starts, to see that every part is properly oiled, and that every screw and joint is tight. If so inspected, once a fortnight would be sufficient to examine the packings of the slides and pistons. The engine man should never quit the engine room during the voyage; and when he sees any accident likely to occur, he should let off the steam and disengage the eccentric. Any of the working parts getting loose, any of the screws getting between the finer parts, or the water getting upon the top of the piston in starting the engine, contribute to injure and break the engine.

Suppose, by any accident, the safety-valve was out of order, and the pressure became too great for the strength of the boiler, and it was to give way, what would be the effect on the boiler? Supposing such a thing, which I conceive is impossible, that the safety-valves should get choked, the steam would come off at the feed pipes. The boilers are calculated to sustain fifty times the pressure required of them. When the boilers are made of malleable iron, and give way, they merely tear and rend; of cast iron, they would fly into pieces like a shell.

When the main hole cover of the boiler is taken off to clean the boiler, the water is exposed to the atmosphere, and becomes chrystalized, and renders them very difficult to clean. It is better to have pumps or cocks to let the water through the side of the vessel from the boiler, without the main hole being opened.

James Brown again called in.—The speed of the James Watt is 10 miles an hour through still water, independent of tide or wind. The power required to double the velocity is as the cube nearly. By increasing the power, you might, in some cases, overload the vessel with the weight of the machinery, and not propel her more than by a small engine.

The weight of two forty-horse power engines would be nearly 100 tons complete, with duplicates; and I should think from 20 to 25 tons more for two fifties. This includes the weight of water, coals, and every other appendage.

I do not think that the cubical content of the boiler has any thing to do with the horse power. The depth of the water in the boiler depends entirely upon the size of the flues and the power required.

In constructing the boiler, the rule now is to carry the smallest quantity of water possible.

Capt. John Percy—Commands the Hero, a steam packet from London to Margate; tonnage 427 tons; 2 engines and 50 horse power; distance 84 miles; passages average 7½ hours, carries also fore and main lug and jib, and a squaresail; do not work with mizens, they carried too much weather helm; paddles 8 feet in the centre, 12 in number, 3½ feet apart; paddles take 17 or 18 inches of water; works 30 strokes per minute; diameter of the wheels 14 feet; draws 6 feet 4 inches.

Joshua Field—Manufactures engines. Built the Sovereign, a steam packet between Dover and Boulogne; 2 engines of 16 horse power; about 100 tons; draws 6 feet 2 inches; beam 16 feet; paddles 5 feet, made of iron curved, 8 paddles; diameter of wheel 9 feet. Those accidents that happened to the boilers arose from carelessness in feeding the boiler, or from want of sufficiently cleaning, or changing of the water. A valve on the top of the cylinder will entirely prevent any damage from the water on the top of the cylinder.

No vessel ever had a sufficient power yet.

Experience has shown that there ought to be one paddle to every foot of diameter of the wheel.

I would place the engines rather before the centre of buoyancy, the boiler rather behind the centre of buoyancy; the axle of the wheel or shaft at the most forward part of the engine. It is important to keep the centre of gravity as low as possible. The bottom of the boilers should be placed as low as possible. The rule of making the boilers is 20 cubic feet to a horse power. To guard against fire, we insulate every part in which the fire acts from the vessel by water, and for that for some way up the chimney, and also the furnaces; the floor is plated with iron.

The boiler ought to be painted once every three months. After each voyage, the boiler ought to be well cleaned, and an examination made of every part of the engine.

The effect of increased pressure upon a very strong engine would be to stop it. Engines are not made strong enough.

Mr. Timothy Bramah.—I have seen the boilers of a boat engine something less than 16 cubic feet per horse power, and they have been made as large as 28 feet. Twenty cubic feet would be sufficient for large engines. An improvement may be made by diminishing the cubical contents of the boiler, without lessening the superficial surface exposed to the action of the fire, as the quantity of steam evaporated in a given time depends upon the surface exposed, and not upon the quantity of water contained in the boiler.

In proportion as the size of the wheel is diminished, greater velocity ought to be given to it. I consider it of importance to have a valve in the top of the cylinder to let off the condensed water. For want of such valve, I have known a beam of an engine to be broken.

Mr. Bryan Donkin examined, a professional Engineer.

It appears to be necessary that one horse's power should be employed for every two feet and about three or four-tenths in the transverse sectional area of the vessel, to give the vessel a velocity of eight miles an hour through the water. This is the only rule with which I am acquainted; if a greater velocity is required in the vessel, a greater power must be employed. The general rule is, that the power to impel the vessel must be as the square of the velocity. There is a little difference arising from the various shapes of

which the vessels are made. To double the velocity, you must quadruple the power. Ten miles per hour, independently of the wind, is a velocity seldom arrived at.

The breadth of the wheel must be in proportion to the power of the engine. The resistance of the water against the paddles depends upon their depth in the water, as well as upon the width of the wheel. I have found, on comparing the wheels of different vessels, that the sectional area, or that part of the wheel immersed in the water, varied; but that about three-tenths of a foot might be taken as the quantity allowed for every horse's power. It is not material what shape the paddles are, provided the area or surface exposed to the sea be sufficient.

It is my opinion that, in by far the greater number of vessels hitherto made, the capacity of the boilers, and the quantity of water they contain, are much too large, and that the fire place, and the surface of flues exposed to the fire and heated air, are too small. By doing so, the vessels have been loaded with a useless weight of many tons, and the engines have been inadequately supplied with steam.

In some instances, I have known the proportion of 20 cubic feet to one horse's power adopted for the contents of the boiler and the power of the engine; that I think far too much. I believe that the quantity of water in a steam boiler for any boat need not be more than eight cubic feet of water per horse.

The quantity of steam supplied to the engine does not at all depend upon the *quantity* of water; it depends entirely upon the size of the fire and the quantity of surface exposed to the action of the fire, provided there be but a sufficient quantity of water to cover the flues. I think the superficial area of the fire should not be much less than one foot to a horse, and the area of the whole surface exposed to the action of the fire need not be more than from ten to twelve superficial feet for every horse's power.

I decidedly prefer copper to iron for making boilers, because the copper may be made thinner, consequently lighter, and it is much more durable. It is not so much exposed to injury from salt water, and steam is obtained faster than in an iron one. If the wrought iron boiler be not very large, I think three-eighths of thickness would be sufficient; for a copper boiler, the bottom is three-eighths, and the sides and top one-fourth of an inch. And, besides, when the boiler is worn out, the old copper is worth nearly as much as the original price of the boiler. There is also a saving in the fuel. They are generally objected to on account of the expense of making them. They are less liable to be injured by the fire than iron boilers.

The effect of negligence in not supplying a sufficiency of water is, that the bottom of the boiler, being unprotected by any water upon it, is heated red-hot, the plates become softened, and the expansion of the steam generally forces them down toward the fire.

The doors of the fire places ought to be opened as seldom, and for as short time as possible, because the cold air rushes in and cools the boiler.

The adjustment of the centre of gravity of the vessel, with the machinery in it, in its bearing with respect to the water line, ought to take place between the center of gravity of the vessel and the centre of buoyancy. The center of gravity of the vessel and its contents ought to be below the center of buoyancy: for, if the center of gravity were to be placed above the center of buoyancy, the vessel would then overturn; and the nearer they approach each other the vessel will be more subject to roll; the lower it is the steadier it will be in the water. A steam vessel for sea should be keel built, which

would give an opportunity of placing the machinery, boilers, &c. and, consequently, the center of gravity, much lower than can be done in a flat-bottomed vessel.

My opinion is, that every thing which, by possibility, could be made of wrought iron, ought to be so made. I would make every part of an engine for sea service at least of three times the strength of that which, by estimation, would be required to resist the power of the engine when in its ordinary state of working, in order that they might effectually resist the violent shocks to which they must necessarily be exposed in a gale of wind and a heavy sea. Accidents are most likely to happen at a time when the suspension of the power of the engine would be the most fatal.

The engine is liable to be broken by suffering the bearings upon which the shafts work, and the links connecting the piston with the beam, to get loose; and, in some cases, making them too tight, so as the bearings heat, and by not attending carefully to the adjustment of the steam valve when the vessel is exposed to a heavy sea.

There is a description of persons commonly employed as engineers on board steam vessels, a set of men accustomed to attend engines, some of them engine makers. In my opinion, no man ought to be employed on board steamboats as a superintendent, or to have the care of an engine, but one who perfectly understands the nature and construction of an engine. Those commonly employed are working men.

Copper boilers will last ten times longer than iron boilers: the latter will last, generally, not more than two or three years.

High pressure engines are not used in this country (England); they are used in America. In the high pressure engine, the boiler is employed, in some instances, to generate steam at the rate of 40 pounds to a square inch; on a low pressure in our engines, not more than from two to four pounds. There need not be more; with this they are perfectly safe. Copper boilers are equally if not more free from being liable to bursting than wrought iron. Sea water has very little action upon copper. I think it essential to ascertain the gravity of the water after every voyage, until it is satisfactorily ascertained how long a boiler will work before the salt is deposited.

I conceive the injury from neglect of engines is greater than the injury arising from the actual working them. It is an advantage in keeping an engine at work as long as possible: because, if it is suffered to get cool, the same degree of heat must be restored to the water and every part of the engine.

I attribute most of the serious accidents to neglect, particularly the accidents to the boilers.

I am of opinion that much may be done towards the improvement of steam vessels by attending to past experience. From repeated failures, we have seen the necessity of a better adaptation of the power of the steam engine to the size of the vessels; of making the vessels and engines of greater strength; of a more suitable selection of materials; of the inutility of using small vessels and small engines for such a purpose; of the necessity of most carefully guarding against fire, by providing a safe receptacle for the coals, and in the construction of the fire-places and boilers; of lessening the quantity of water in the boiler; of preventing the deposition of salt; and of increasing the size of the fire-places and flues of the boilers, so as to lessen the labor of the men, and secure an ample supply of steam.

Mr. M. J. Brunel, called in, and examined—Says: That, with respect to the form of the vessel, the best water lines are desirable for navigating

consistently, however, with the depth of water that may be permitted, according to the navigation. The power of the engine should not be cramped by short strokes.

The defects in the machinery now complained of do not arise so much from their mechanical arrangement, since they are found to perform so well in easy navigation, as from the nature of the service they have to perform, when they are contending against a heavy head sea and a tempestuous wind. It is in these circumstances that the irregularity, sometimes the deficiency, and, accidentally, the total abscence of the resisting medium, that throws the ungoverned and almost irresistible power of the steam engine into those convulsive starts that meet with no other controlable check but the arm of the crank, from which it recoils with increased energy to the opposite side, occasioning thereby those destructive shocks, those alternate strains and wrenchings, which, on frequent recurrence, must prove fatal to the cranks and to the shafts, besides other parts of the machinery. I would apply the power more directly upon the crank. The crank is the most simple, and, on that account, the most eligible agent we are acquainted with in mechanics for effecting a rotary movement from an alternate power.

I think that vessels engaged in making sea voyages through all times of the year, and in all weathers, have, in general, employed more power than is required, from which it results that the weight of the boilers, of the fuel, and of a ponderous machinery, are extremely disadvantageous, as it has been found in several instances, when, with a view of making some additions or improvements, they have turned out to be productive of worse effects by lessening the buoyancy. These circumstances very materially counteract the object of high power. An excess of power always cramps the machinery, and the short strokes are incalculably bad.

For a vessel of 200 tons burthen, to be used at sea, I should prefer having two engines of 30 horse power to two of 40 horse power, where speed is the only object in view: but, for a safe and steady navigation, under all circumstances, I should adopt the smaller power as being sufficient, and, consequently, preferable.

Sir Isaac Coffin, Bart., a member of the committee, examined—Says: In the general average of salt water, there is a gallon of salt to thirty-three and a half of salt water; consequently, when the steam, being the aqueous parts of the water, are expelled, the salt is left behind, which adheres to the bottom of the boiler in the shape of a crust, and tends to precipitate the destruction of the bottom of the boiler. This should be removed once a week.

Mr. Michael Farraday examined—Says: I am chemical assistant to the Royal Institution, and have turned my attention to the action of salt water, and the salts it contains, on iron and copper. The principal source of injury to iron arising from the salts contained in sea water, when they remain by evaporation, result from the presence of the salt called muriate of magnesia. When in solution, it acts more on iron than its accompanying salts, and when dry it is decomposed at a heat of 270° of Fahrenheit and upwards, liberating muriatic acid; and this immediately acts upon the metal much more strongly than any other substance which the water contains. Hence, besides the burning of the boiler, which takes place when the metal is coated by the salts, there is this additional strong action from the liberation of the free acid. This action upon the metal causes its oxydation, and forms a soluble salt with it. This acid acts both when in solution and in the gaseous state. If the water were evaporated from the boiler, so that the salts should

become dry on any part of it, and sufficiently hot, then the acid gas would pass into the steam passages and into the cylinder. This injury could only happen in the low pressure engines by neglect of the engineers in giving a sufficient supply of water.

The muriate of magnesia existing in sea water is constantly acting upon the metal with which it is in contact, and is four or five times more injurious than equal quantities of the other salts in salt water. Beside the muriate of magnesia, other salts are deposited: muriate of soda, muriate of lime, sulphate of lime, and some other salts in very minute quantities. None of these salts injure the metal so much as the muriate of magnesia, and none of them liberate muriatic acid by heat alone. The difference of action upon iron and copper is very considerable. Upon copper it is very little. The formation of the salt in crusts upon the bottom of the boiler very much diminishes the action of the fire upon the water in producing steam.

I have tried experiments to ascertain the manner in which the different salts contained in salt water are deposited by heat. Taking 1,000 parts of sea water by weight and evaporating, I found that 825 parts nearly of steam could be driven off before any deposition commenced, but then sulphate of lime was deposited, on proceeding with the evaporation, till about 110 parts remained, the common salt began to chrystalize and deposite; on continuing the evaporation till only about 35½ parts remained, the muriatic acid from the decomposition of the muriate of magnesia began to separate. If the whole of the steam were condensed and returned into the boiler, there would be no concentration of the water contained in it; but if there is a loss of steam, and sea water be supplied to the boiler in its place, a deposition of salt will take place, more or less rapidly, according to the loss of steam. About eight-ninths, not quite nine-tenths of the water contained in the boiler may be raised into steam before the salt is deposited. There would be no difficulty in supplying hot sea water, and in withdrawing the concentrated water in the boilers in such a manner as to preserve the whole mass below the point of deposition. It is the only mode that occurs to me of preventing the salts from being deposited in the boilers, and I think it easy to put in practice. If this operation were resorted to, the water in the boiler would never be in a state to deposite chrystals.

Those salts, when decomposed, fasten strongly on the metal, firmly adhering to the bottom, requiring considerable labor to pick it up, and prevent, to a considerable extent, the transmission of heat through the bottom of the boiler to the water. This renders necessary considerably more fuel to raise the same quantity of steam.

The cubic foot of sea water weighs about 1,026½ ounces avoirdupois; it contains 3.28 ounces of muriate of magnesia, which, if completely decomposed by heat, would give rise to 2.13 ounces of muriatic acid: this is able to dissolve or corrode 1.6 ounces of iron; and if it were found useful to decompose this muriate of magnesia, it would require 1.64 ounces of quick lime, or 2.78 ounces of dry potash, or 4.1 ounces nearly of common pearl-ash.

Mr. M. Farraday again called in, and examined, says: That the lower the temperature, the more favorable for the deposition of the salt. If a certain quantity of sea water be taken, 1,000 parts for instance, the following are the points of deposition: the boiling point of the water at first is nearly 214°; when 701 parts of steam have been driven off, the remaining 299 parts begin to deposite sulphate of lime, the boiling temperature being then 217°; when 898 parts have been evaporated, the remaining 102 parts begin to deposite common salt, and boil at 228°; if all the water be evaporated, about 30 parts

of salt remain. These are the points which occur in a close vessel at the pressure of the atmosphere. I have made these experiments very carefully and am willing to trust to it.

In the evidence before this committee I have read, mention is made of crusts of salt having formed on the bottom of boilers; the interposition of these crusts, which are very bad conductors of heat between the boiler and the water, prevents the free transmission of heat that ought to take place; and the bottom of the boiler, with the under side of the crust, is, in consequence, heated to a higher temperature than the water itself; this undue accession of heat, increasing with the thickness of the crust, when the elevation of temperature reaches 270° or 280°, and upwards, all that portion of muriate of magnesia included in the crust so heated, will be decomposed, and its muriatic acid evolved in a free state; also, if by carelessness the sea water in a boiler, having the flue passing through it, should be suffered to sink by evaporation below that flue, any salt deposited on the surface of it would then be liable to an elevation of temperature much above 270° or 300°, and would, in consequence, have the muriate of magnesia contained in it decomposed, and the muriatic acid evolved.

The following numbers are very nearly correct, and accord with the best analysis. Its specific gravity varies a little in different parts of the ocean from the vicinity of mouths of rivers, ice, evaporation, and other causes, but may be estimated as a mean at 1,027, pure water being 1,000. When of a specific gravity of 1027.2, being such as I used in my experiments, one cubic foot of it weighs 1026.265 ounces avoirdupois, and contains

Common salt - - - -	25.762 ounces;
Muriate of magnesia - - -	3.282
Sulphate of magnesia - - -	2.212
Sulphate of lime - - - -	1.013
	32.27

besides small quantities of some other salts.

Taking 1000 parts by weight of sea water, 701 parts may be converted into steam before any deposite at all takes place in it; and that 898.3 parts of steam may be obtained before any common salt will be deposited. Sea water, boiling at common pressure at less than 217° Fahrenheit, is not depositing any thing; and that boiling at temperatures below 228° is not depositing common salt.

It is now easy to ascertain the propriety of changing the water in a boiler. If the water left in it at the end of the voyage is less than three-tenths of the whole quantity introduced, it will deposit sulphate of lime; if it is less than one-tenth, it will deposite common salt; and the more the diminution below these quantities the greater the depositions.

No. 32.

Inquiries and Observations on the Comparative Power of Steam Engines.

To the Editor of the London Mechanics' Magazine:

Sir: As a great deal has been said, from time to time, respecting the most accurate mode of calculating the horse power of a steam engine, I beg to make the following statements for the information of your intelligent readers.

Boulton and Watt, Mr. Maudsley, and Mr. Fawcet, of Liverpool, have each lately finished, and set to work, in three steam vessels of similar ton

nage, three pairs of 70 horse power engines. The two 70s, furnished by Boulton and Watt, are of the following dimensions:

Diameter of each cylinder - - - -	in. 44½
Length of the stroke - - - -	54
Those by Maudsley are,	
Diameter of each cylinder - - - -	47
Length of the stroke - - - -	54
By Mr. Fawcet, of Liverpool, are,	
Diameter of each cylinder - - - -	46½
Length of the stroke - - - -	51

Query. Which of these are the most correct in their proportions?

Comparative proportions of Steam Engines.

Sir: Your correspondent, who has stated, as above, the diameters of the cylinders and lengths of stroke of three steam engines of 70 horse power, lately made for steam vessels by Messrs. Boulton and Watt, Mr. Maudsley, and Mr. Fawcet, has omitted to mention the number of strokes which the different engines are intended to make per minute. This is an essential particular for any computation on the power which an engine can exert; for, other circumstances being similar, the powers of steam engines will be proportionate to the quantity of steam expended by them in a given time; so that a smaller cylinder, whose piston moves quicker than that of a larger one, may exert a greater power.

The proportions originally established by Mr. Watt for the cylinders of his engines of different powers, are such as to allow 33.1 cubic feet of steam per minute, to produce each horse power.

For instance, his 40 horse engine had a cylinder 31½ inches diameter, and the piston made 17½ double strokes per minute, of 7 feet each, so that it passed through 245 feet per minute. The area of a circle, 31½ inches in diameter, is 779 square inches, or 5.41 square feet, which, being multiplied by 245, gives 1,325 cubic feet of steam expended per minute, by the motion of the piston, without making any allowance for the extra quantity expended by waste of condensation or leakage. This is at the rate of 33.1 cubic feet per minute for each horse power.

Again, his 20 horse engine had a cylinder 23¾ inches diameter; its piston made 21½ strokes per minute, of 5 feet long, or it moved 215 feet per minute. The expenditure of steam was 662 cubic feet per minute, or equal to 33.1 cubic feet per minute for each horse power.

This allowance has been followed ever since by Messrs. Boulton and Watt, in their large engines for manufactories, though they have, in many cases, reduced the lengths of the strokes, and enlarged the diameter of the cylinders. For instance, their modern 40 horse engine has a cylinder of 32½ inches diameter, and the piston makes 19 double strokes per minute, of 6 feet each, or it moves 228 feet per minute, which is an expenditure of 1304 cubic feet of steam per minute, or a little less than Mr. Watt's old engine, though the cylinder of the latter is smallest.

If 33 cubic feet per minute is allowed for each horse power, then the effective pressure upon each square inch of the piston will be 6.944 pounds per square inch, without any deduction for friction or imperfect exhaustion. The following rule is adapted to this proportion:

No. 33.

To find the power of a Steam Engine, on Mr. Watt's principle, in horse power.(1)

RULE. Multiply the square of the diameter of the cylinder in inches by the motion of the piston in feet per minute, and divide the product by 6050; the quotient is the power of the engine in horse power.(2)

EXAMPLE. Cylinder 23¾ inches diameter, squared, = 564 circular inches area, × 215 feet motion per minute, = 121,260 cylindrical inch feet of steam expended per minute, ÷ 6050 = 20 horse power.

The calculation may be conveniently performed by the two lines marked C and D, upon a sliding rule, when the slider is set in the following manner:

Sliding rule.		
C	feet per min.	Horse power of Eng.
D	246(3)	Diam. of cylin. inch.

The above may be depended upon as an authentic rule for Mr. Watt's engines on shore. It should be observed, that a properly constructed engine, with a sufficient boiler, is capable of exerting full half as much more as its nominal power; so that a 40 horse engine, with a suitable increase of fuel, is able to do the work of 60 horse power, or a 20 horse engine can exert 30 horse power. In this respect, the old engines, such as were constructed by Mr. Watt himself, are greatly preferable to their descendants of the present day, which, in performing their evolutions with a more quiet motion, have lost much of the activity of their noisy progenitors.

In steam vessels, it would be useless to load the vessel with any more weight than is absolutely necessary, and hence it is the uniform practice to urge the engines on board such vessels to their very utmost power, the throttle-valve being always kept fully open when the vessel is under weigh; and as such engines have an unlimited command of cold water for condensation, they may be considered as always exerting half as much more power as they are rated at, or that two 40 horse engines always exert 120 horse power; two 50's, 150 horse power; two 60's, 180 horse power; and two 70's, 210 horse power. The best steamboat engines exceed even this proportion considerably.

If your correspondent can state with certainty the number of strokes each of the seventy horse engines is intended to make, the diameters of their paddle wheels, the length and breadth of those paddles, their number, how much they dip into the water, and the dimensions and draught of water of the vessels, their names, the services they are employed in, the speed with which they move through still water, and any other particulars, it would be very useful and interesting to many of your readers.

P. S. I have been told that Mr. Maudsley's cylinders are 46½ inches, but your correspondent says 47.—[*Franklin Journal, &c.*, vol. 3, p. 334, &c.

On the Explosion of Steam Boilers.

It has been generally considered a well established fact, that the caloric of steam, at a given elasticity, is invariably the same when in contact with water; but this is far from being the case. It may be, and often is, so gene-

(1) A horse power is that exertion of moving force, which, besides overcoming all friction, will raise 33,000 pounds' weight one foot high per minute.

(2) The divisor, 6050, is the number of cylindrical inch feet (i. e. small cylinders one inch diameter, and one foot long) that are contained in 33 cubic feet; for a square foot contains 183.346 circular inches × 33 = 6050.42.

(3) The number 246, which is used as a gauge point on the line D of the sliding rule, is the square root of nearly times 6050 or 60,516; or the number 77.78, which is the square root of 6050, may be used for the gauge points, and will give the same result as 246.

rated as to indicate very high degrees of temperature, without a corresponding increase of power, so as evidently to prove that temperature alone cannot be relied on as a measure of the elastic power of steam. Many experimentalists have thus undoubtedly been led into error, especially in reference to high temperatures. If any part of the boiler which contains the steam be suffered to become of a higher temperature than the water contained in it, from want of a sufficient supply, the steam will readily receive an excess of caloric, and become surcharged with it, without acquiring proportional elasticity. In some recent experiments, I have heated steam to a temperature that would have given all the power that the highest steam is capable of exerting, which would have been 56,000 pounds to the square inch, if it had had its full quantum of water: yet the indicator showed a pressure of less than five atmospheres. Having satisfied myself, by repeated experiments, as to the certainty of this curious fact, the thought struck me, that if heated water were suddenly injected into the superheated steam, the effect would instantly be, the formation of highly elastic steam, the strength of which would depend upon temperature, and quantity of the surcharged steam, and of the water injected. To ascertain the truth of this theory, I made the following experiments:

A generator was filled with water, and heated to about 500 degrees, and, consequently, exerted a force of about 50 atmospheres; but the pressure value being loaded to about 60 atmospheres, it prevented the water from expanding into steam. The receiver, which was destitute both of water and of steam, was heated to about 1200 degrees: a small quantity of water was injected into the generator by the forcing pump, which forced out, from under the pressure valve, into the receiver, a corresponding quantity of heated water, and this instantly flashed into steam; which, from its having ignited the hemp cord that covered the steam pipe, ten feet from the generator, must have been at a temperature of at least 800 degrees, which would be equal to about 80 atmospheres; but, from want of water to give it its necessary density, the indicator showed a pressure of about 5 atmospheres. Whether the pressure of the steam, which was rushing through the steam pipe, was at 5 or 100, or more atmospheres, the steam pipe kept up at the high temperature before mentioned, which I attributed to the steam being surcharged with caloric. The pump was now made to inject a much larger quantity of heated water, and the indicator showed a pressure of from 50 to 80 atmospheres; the throttle-valve being partly opened, it soon expanded to the former pressure of about 5 atmospheres. The water was then injected again and again, and the indicator was observed to oscillate at each stroke of the pump, from 5 to between 40 and 100 atmospheres, according to the quantity of water injected, clearly showing that, at this reduced pressure, there was a great redundancy of heat, with little elastic force. It soon occurred to me, that to this might be traced the true cause of the tremendous explosions that suddenly take place in low as well as in high pressure boilers.

There are many instances where, immediately before one of these terrific explosions had taken place, the engine labored, showing evidently a decrease of power in the engine. To illustrate the theory of sudden explosions, let us suppose the feed pipe, or pump, to be choked; in this case, the water would soon sink below some parts of the boiler, which should be constantly covered by it, thus causing them to become heated to a much higher temperature than the water. The steam now being in contact with the heated

metal, readily takes up the heat, and becomes surcharged with it.(4) Since caloric will not *descend* in water, it cannot be taken up by the water which is below it. The steam thus surcharged will heat the upper surface of the boiler, in some cases, *red hot*, and will ignite coals, or any other combustible matter, which may be in contact with it. If the water which is kept below the surcharged steam, by the pressure of it, should, by any circumstance, be made to take up the excess of caloric in the steam, as well as that from the upper part of the boiler, which has become heated above the temperature of the water, in consequence of the water having been allowed to get too low, it will instantly become highly elastic steam, and an explosion cannot be prevented by any safety-valve hitherto used.

To show how the water may be suddenly brought in contact with the overheated parts of the boiler, as well as with the surcharged steam, it will be necessary to state the following facts:

As long as water is not heated above 212 degrees, it will simply boil, and give off atmospheric steam, without the water having any tendency to rise with it; but, as it becomes more and more elevated in temperature, its disposition to rise with the steam becomes more and more apparent. As the steam presses on the surface of the water, in the same ratio as the water increases in temperature, it only boils without rising, as when at atmospheric pressure; but if the steam should be drawn off faster than it is generated, this artificial pressure would be taken off, and the water would rise with the steam in proportion to the suddenness and rapidity of its escape. The water and steam, in this mixed state, thus filling every part of the boiler, the excess of caloric in the surcharged steam, as well as the extra heat from the boiler, will be instantly taken up by the water which rises with the steam, by which means the steam becomes sufficiently dense (or powerful) to produce the fatal effects too often experienced, not only from high but from low pressure boilers. If, for instance, the water (as has been before noticed) should be suffered to get below any part of the boiler which is exposed to the fire, the steam will soon become surcharged with heat. If a boiler, thus circumstanced, should have the weight taken from the safety-valve,(5) or a small rent be effected in the boiler from its giving way by the pressure of the steam, an explosion will be sure to follow. A remedy for this kind of explosion, which appears to be the only serious one, is that of not allowing the water to subside below any part of the boiler which is exposed to the fire. In case the water should settle, it may be known by having a tube, with its upper end trumpet-mouthed, and its lower end fixed in the boiler, entering a few inches below the surface of the water; then, as soon as it subsides sufficiently to allow the steam to blow off, the blast will give warning that no time should be lost in supplying water, or checking the fire. When highly surcharged steam is rushing from the safety-valve, or any other aperture, it may be known by its perfect invisibility, even in the coldest day, nor can it be seen at any distance from the valve or cock: it is, however, condensible, as may be seen by holding any cold substance in its range.

[*Franklin Journal, &c.*, vol. 3, p. 417.

(4) Practical engineers have frequently witnessed the destruction of the packing of pistons, by their becoming charred, although the steam issuing was in contact with the water, the temperature of which did not exceed 230 degrees. It is very evident that this steam was surcharged with heat, and was much above the temperature of the water upon which it was reposing, and in a suitable state to produce explosion, had the water been allowed to rise with the steam, by drawing it off faster than it was generated.

(5) Some of the most dreadful accidents from explosions which have taken place, have occurred from low pressure boilers. It is, I believe, a fact, that more persons have been killed by *low* than by *high* pressure boilers. High pressure boilers have since been substituted.

[*Franklin Journal, &c.*, vol. 3, p. 335, 418, 420.

No. 34.

Facts and observations on the Bursting of the Boilers of Steam Engines.

By Erskine Hazard, Esq., Civil Engineer.

The frequency of disasters arising from the bursting of boilers in steamboats, both with high and low pressure engines, makes it the imperious duty of all those who have given particular attention to the subject, to make public any ideas which may throw light on the cause of them, as they may thereby aid in preventing their repetition. With this view, I take the liberty of sending you the following explanation, which was given to me by our countryman Perkins. He builds his theory on the ground that the power of steam does not depend upon *temperature* alone, but principally upon the *quantity of water* that is contained in a given bulk of it; in other words, that its power is derived from its compression. This corresponds with the experience of the late Colonel Alexander Anderson, who gave me the same theory many years since, and at the same time informed me that, when distilling by steam, he uniformly found *the quantity of liquor* produced in a given time to be in exact proportion to *the pressure within* his still. He hence concluded that atmospheric steam, confined in any vessel in such a manner that it could not get an additional supply of water, might be *heated red hot* without bursting the vessel, or increasing its power. Perkins states that he has completely realized this idea in his experiments. He also mentions a fact communicated to him by Mr. Williams, principal manager of the Dublin and Liverpool Steam Company, which was this: The people on board the boat were alarmed, while on their voyage, by the smell of pine smoke, and concluded that the boat must be on fire; but, upon searching, they found a piece of pine wood on the top of one of the boilers, which was nearly burnt to a coal; it was in such a situation, that no fire could have communicated with it, except through the top of the boiler. The engine at the time was working with steam only a few pounds above the atmospheric pressure. Upon mentioning this circumstance to the captain of one of our Delaware steamboats, he informed me that the leaden joints of his steam pipe were once melted, when the steam gauge indicated only the pressure at which they usually worked. In both these cases, the water was so low in the boilers, that the heat was communicated to the steam through a portion of the boiler which had no water in contact with it, and which, of course, became red hot, while the steam could not part with its heat *downwards* to the water.

The *repellent power of heat* is the proximate cause of explosion, according to Perkins's theory. This was one of the principal obstacles he met with in the progress of his experiments on high steam. In his tabular generators, he found it impossible to keep the water *in contact* with the metal, when a great heat was applied, until he adopted the expedient of the pressure valve, loaded with five atmospheres more than the pressure of the steam. The water was, as it were, *wire drawn*, or passed through the *centre* of the tubes in a fine thread, being repelled by the heat of the sides, which increased to redness, and finally destroyed the tubes. To show this repellent power of heat, he made a hole of one-fourth of an inch diameter in one of his generators, and adapted a plug to it, which was removed when that part of the tube became red hot; no steam or water escaped from it, notwithstanding the steam gauge indicated a very high pressure: a wire was introduced into the hole, to ascertain that it was free. The generator was then suffered to cool to a black heat, when the steam commenced issuing from the hole with great violence. Another experiment was to heat two

cast iron bowls of equal dimensions, the one black, the other red hot, and then to pour equal quantities of water into both: the cooler bowl uniformly evaporated the water first. From the above facts, Perkins's explanation of the bursting of boilers will, I think, appear very plausible. It is this: that the water is suffered to get so low as to bring a portion of the boiler, not covered with water, in contact with the fire; this becomes red hot, and imparts its heat to the steam. The redness gradually extends itself below the water, which is at length repelled from the boiler, and thrown up among the *hot steam*, (like a pot suddenly boiling over,) which surcharged steam, immediately imparting its *excessive* heat to the water, forms steam of the greatest power, and occasions the disastrous explosions.

The bursting of the boiler of the Ætna was attributed to the supply pipe being choked. To this, then, the theory is perfectly applicable.

PHILADELPHIA, *April* 16, 1827.

[*The Franklin Journal, &c.*, vol. 3, p. 421, &c.

On the Relative Proportions of the various parts of the Boulton & Watt's, or Low Pressure, Steam Engine; the fuel required for working engines of different powers; and the effect produced in pumping water or grinding wheat.

We have been furnished with a copy of a table containing the very important results of the experience of Boulton and Watt in proportioning the most essential parts of their steam engines, together with some other particulars, a knowledge of which ought to be possessed, not only by the manufacturer of those machines, but also by every engineer. This table has never before appeared in print, but manuscript copies of it are possessed by the principal engineers of Great Britain, from one of whom it was procured by an American engineer, who has recently visited that country.

The preceding article on the comparative proportions of steam engines, which we have extracted from a late number of the London Mechanics' Magazine, is, manifestly, written by a person well acquainted with the subject upon which he treats, and will, in several respects, be a useful introduction to this table, which we have subjoined.

In these tables, the calculations, it will be seen, are made for steam of two pounds to the square inch; and, when the pressure is greater, the calculations must, of course, be so modified as to suit this variation. For the sake of the general reader, it may be well to observe, that, by two pounds to the square inch, is intended two pounds above the ordinary pressure of the atmosphere, making, of course, about 17 lbs. on every square inch of the surface of the piston. If the pressure exceed four pounds upon the square inch, it is no longer a true low pressure engine, and, in this country, there are very few of this kind. Those denominated low pressure, and used on board our steamboats, work, ordinarily, under a pressure of from 7 to 14 lbs. upon the inch; and, as the boilers are made strong in proportion, and varied in their form, so as to sustain this pressure, they are, under proper management, equally safe with those of lower pressure.

The table supposes the working pressure upon every square inch of the piston to be equal to ten pounds; but, in the low pressure engine, it would be accounted a good average to equal one-half of the elastic power of the steam, which, at 17 lbs. to the inch, would amount to 8½ lbs., one-half the power being expended in overcoming friction and inertion, and in unavoidable imperfections in workmanship.

[*Franklin Journal, &c.*, vol. 3, p. 336, &c.

On the Relative Proportions of the various parts of the Boulton and Watt's, or Low Pressure, Steam Engine; the fuel required for working engines of different powers, and the effect produced in pumping water or grinding wheat. (Steam two pounds to the square inch.)

CYLINDER.					
No. of horses' power.	Inches diameter.	Inches area.	Inches contents.	Strokes.	
				Length.	No. per min.
1	6	28.274	508.932	1.6	60.
2	9	63.617	1526.808	2.	50.
4	12	113.1	3393.	2.6	40.
6	14	153.94	5541.84	3.	33.3
8	16	201.062	8444.52	3.6	28.571
10	17.5	240.53	11545.44	4.	25.
12	18.75	275.117	13205.616	4.	25.
14	20.2	320.474	17305.596	4.6	22.2
16	21.5	363.65	19604.7	4.6	22.2
18	22.8	408.28	24498.	5.	20.
20	24.	452.4	27144.	5.	20.
22	25.2	498.76	29925.6	5.	20.
24	26.3	543.41	35865.06	5.6	18.18
26	27.3	585.35	38633.1	5.6	18.18
28	28.4	633.5	45612.	6.	16.6
30	29.5	683.5	49212.	6.	16.6
32	30.3	721.08	51917.76	6.	16.6
34	31.2	764.54	59634.12	6.6	15.38
36	32.2	814.34	63518.52	6.6	15.38
38	33.1	860.5	72282.	7.	14.28
40	34.	908.	76272.	7.	14.28
42	34.75	948.42	79667.28	7.	14.28
44	35.6	995.4	91576.8	7.6	13.3
46	36.4	1040.62	95737.04	7.6	13.3
48	37.2	1086.87	104339.52	8.	12.5
50	38.	1134.12	108875.52	8.	12.5
52	38.7	1176.29	112923.84	8.	12.5
54	39.5	1225.42	12492.984	8.6	11.7647
56	40.2	1269.24	129562.48	8.6	11.7647
58	40.8	1307.	141156.	9.	11.
60	41.6	1359.18	146791.44	9.	11.
62	42,25	1402.	151416.	9.	11.
64	43.	1432.2	154677.6	9.	11.
66	43.6	1493.014	161145.08	9.	11.
68	44.25	1537.86	166088.88	9.	11.
70	45.	1690.44	171767.52	9.	11.
72	45.6	1633.13	176378.04	9.	11.
74	46.25	1682.02	181658.16	9.	11.
76	46.8	1720.21	185782.68	9.	11.
78	47.5	1772.06	191382.48	9.	11.
80	48.	1809.56	195432.48	9.	11.
82	48.6	1855.08	200348.64	9.	11.
84	49.2	1901.17	205326.36	9.	11.
86	49.8	1947.82	210364.56	9.	11.
88	50.4	1995.04	215464.32	9.	11.
90	51.	2042.725	220614.3	9.	11.
92	51.5	2083.077	224972.316	9.	11.
94	52.	2123.72	229361.76	9.	11.
96	52.6	2173.	234404.	9.	11.
98	53.2	2222.87	240069.96	9.	11.
100	53.75	2269.07	272288.40	10.	10.

TABLE No. 2.

No. of horses' power.	AIR PUMP.				CONDENSER.
	Inches diameter.	Inches area.	Stroke.	Contents.	Contents ⅓ of cylinder.
1	4.	12.5664	.9	113.1	170.
2	6.	28.2744	1.	339.3	509.
4	8.	59.2656	1.3	714.	1131.
6	9.3	76.93	1.6	1334.74	1847.28
8	10.6	88.25	1.9	1853.25	2814.5
10	11.6	105.683	2.	2536.402	3848.5
12	12.3	118.823	2.	2851.756	4401.872
14	13.3	139.93	2.3	3751.11	5768.532
16	14.3	160.606	2.3	6336.374	6535.
18	15.2	181.459	2.6	5443.77	8166.
20	16.	201.062	2.6	6031.872	9048.
22	16.8	221.671	2.6	6650.138	9975.2
24	17.53	241.354	2.9	7964.686	11955.
26	18.3	263.02	2.9	8679.74	12877.7
28	18.93	281.444	3.	10131.987	15204.
30	19.66	303.57	3.	10928.52	16404.
32	20.2	320.474	3.	11537.086	17306.
34	20.8	339.8	3.3	13252.2	19878.
36	21.5	363.05	3.3	11459.	21172.84
38	22.	380.1336	3.6	15965.6112	24094.
40	22.6	401.151	3.6	16848.342	25424.
42	23.13	420.186	3.6	17647.835	26555.76
44	23.73	442.269	3.9	19902.105	30525.6
46	24.3	463.77	3.9	20869.68	31912.35
48	24.8	483.052	4.	23186.516	34780.
50	25.3	502.7267	4.	24130.8809	36291.84
52	25.8	522.8	4.	25094.4	37641.28
54	26.3	543.41	4.3	27713.93	41664.28
56	26.8	563.1	4.3	28718.39	43187.5
58	27.2	581.07	4.6	31377.8	47052.
60	27.73	604.	4.6	32616.	48930.5
62	28.16	622.81	4.6	33611.79	50472.
64	28.66	645.1241	4.6	34836.7016	51559.2
66	29.06	663.2574	4.6	35815.9	53715.
68	29.5	683.5	4.6	36909.	55363.
70	30.	706.86	4.6	38160.44	57255.84
72	30.4	725.835	4.6	39195.104	58792.68
74	30.83	746.514	4.6	40311.756	60552.72
76	31.2	764.54	4.6	41285.16	61927.56
78	31.6	784.27	4.6	42350.58	63794.16
80	32.	804.25	4.6	43429.5	65146.16
82	32.5	829.578	4.6	44797.252	66783.
84	32.8	844.9647	4.6	45628.0957	68442.
86	33.2	865.7	4.6	46747.8	70121.52
88	33.6	886.685	4.6	47881.	71821.44
90	34.	907.922	4.6	49027.809	73538.3
92	34.33	925.6323	4.6	49984.1445	74998.8
94	34.66	943.513	4.6	50949.716	76454.
96	35.	959.75	4.6	51827.	78134.66
98	35.46	987.571	4.6	53328.837	80023.32
100	35.83	1008.288	5.	60497.280	81616.52

TABLE No. 3.

No. of horses' power.	INJECTION WATER.		BOILER.	COALS FOR 12 HOURS.		PUMPING.	GRINDING.
	Gallons per stroke.	Gallons per min.	Contents in galls.	Bushels. Empty.	Bushels. Loaded.		Winchester bush. wheat per hour.
1	.176	7.	24.5	.5	1.5	Ten pounds' working pressure on the square inch of the piston will raise water 20 feet by a pump of the same diameter and stroke with the piston.	1.885
2	.26	13.	49.	1.	3.		4.241
4	.5	20.	98.	2.	6.		7.54
6	.848	28.	147.	3.	9.		10.2
8	1.26	36.	196.	4.	12.		13.4
10	1.72	43.	245.	5.	15.		16.0353
12	2.	50.	294.	6.	18.		18.34
14	2.5675	57.	343	7.	21.		21.
16	2.882	64.	392	8.	24.		24.2154
18	3.6	72.	441.	9.	27.		27.88
20	4.	80.	490.	10.	30.		30.16
22	4.4	88.	539.	11.	33.		33.25
24	5.2805	96.	588.	12.	36.		36.2272
26	5.725	104.	637.	13.	39.		39.0232
28	6.9306	112.	686.	14.	42.		42.226
30	7.4257	120.	738.	15.	45.		45.567
32	7.9207	128.	784.	16.	48.		48.072
34	8.84	136.	833.	17.	51.		51.
36	9.36	144.	882.	18.	54.		54.2887
38	10.71	152.	931.	19.	57.		57.367
40	11.2	160.	980.	20.	60.		60.53
42	11.76	168.	1029.	21.	63.		63.2347
44	13.233	176.	1078.	22.	66.		66.36
46	13.834	184.	1127.	23.	69.		69.3747
48	15.36	192.	1176.	24.	72.		72.458
50	16.	200.	1225.	25.	75.		75.608
52	16.64	208.	1274.	26.	78.		78.4193
54	17.85	216.	1323.	27.	81.		81.6947
56	19.04	224.	1372.	28.	84.		84.616
58	20.9	232.	1421.	29.	87.		87.13
60	21.621	240.	1470.	30.	90.		90.612
62	22.342	248.	1519.	31.	93.		93.53
64	23.063	256.	1568.	32.	96.		96.
66	23.783	264.	1617.	33.	99.		99.53
68	24.504	272.	1666.	34.	102.		102.524
70	25.22	280.	1715.	35.	105.		106.03
72	25.945	288.	1764.	36.	108.		109.
74	26.6	296.	1813.	37.	111.		112.1347
76	27.3838	304.	1862.	38.	114.		115.
78	28.1171	312.	1911.	39.	117.		118.1373
80	28.82	320.	1960.	40.	120.		121.
82	29.549	328.	2009.	41.	123.		123.672
84	30.27	336.	2058.	42.	126.		126.7447
86	30.9	344.	2107.	43.	129.		129.8547
88	31.70	352.	2156.	44.	132.		133.
90	32.43	360.	2205.	45.	135.		136.18167
92	33.153	368.	2254.	46.	138.		138.8718
94	33.173	376.	2303.	47.	141.		141.5813
96	34.594	384.	2352.	48.	144.		144.87
98	35.315	392.	2401.	49.	147.		148.2
100	40.	400.	2450.	50.	150.		151.2713

No. 35.

Extracts of a letter from Jacob Perkins, Esq. to Doctor Thomas P. Jones, dated

LONDON, *March* 8, 1827.

"To prove the safety of my engine, I have worked it under a pressure of 1,400 lbs. to the square inch, or at a hundred atmospheres, and cut off the steam at one-twelfth of the stroke; this was merely to manifest what could be done with perfect security. My usual pressure is 800 lbs. per inch, cutting off at one-eighth, and letting the steam expand to below 100 lbs. per inch."

"My belief is, that water cannot be brought into contact with water heated to about 1,200°, without a force equal to the maximum pressure of steam, which is equal to about 4,000 atmospheres, when water is heated to about 1,200°. That pressure would, I believe, keep it in contact with iron at any degree of heat, and the steam would then be as dense as water."

"The account of my engine, in the "London Journal of Arts, &c.," should have stated that the piston was eight inches in diameter, that it was a twenty-inch, single stroke engine, a good 70 horse power, and consuming but one-fourth of the coal of a condensing engine. The weight on the end of the lever was 300 instead of 150 pounds. You may, my dear sir, depend upon what I have written; it is the result of actual experiment, and there is no fallacy in it. Having succeeded in making a piston which requires no oil, I am determined to ascertain the limits to which pressure can be carried. I am now making a small engine, strong enough to bear 2,000 lbs. per inch, and, when done, you shall know the result. Nothing but the piston will limit the power."—[*Franklin Journal, &c.*, vol. 3, p. 412.

No. 36.

Extract from the observations on Perkins's Improved Steam Engine, by the Editor of the London Journal of Arts, &c.

"Mr. Perkins's original idea of substituting *pressure* for *surface*, in generating steam, (which appears to be the basis of his invention,) has never for a moment been abandoned; and the invention, if satisfactorily established, must certainly be considered as of the utmost importance, particularly in its first feature, *absolute safety*, which could hardly have been contemplated in any other plan of boiler, to the extent which this construction evidently exhibits the capability of effecting. From the mode of constructing the compound generator, as now adopted, it becomes a safety-valve of itself; for the pressure is divided into so many compartments, that any one of them may explode with impunity, without even disturbing a brick of the furnace. Although, in the early part of the invention, many explosions took place, without any attending accident, (which served to show the safety of this method of generating steam, as well as to point out the proper way of constructing the generators,) yet, for the last two years, it is said nothing of the kind has taken place, notwithstanding the steam has been frequently raised to a pressure of above 1,500 lbs. to the square inch.

"We should not have dwelt so long on this part of the invention, had not the alarm, from the great number of explosions within the last year or two, not only in this country, but in France and America, created universal terror, particularly in steamboat travelling; and the danger of explosion would be still more alarming, since it has been recently discovered that the safety-valve is of no use when an explosion takes place from the sudden generation of steam.—[*Franklin Journal, &c.*, vol. 3, p. 415.

EXPLANATION OF THE PLATES.

Fig. No. 1.

A TRANSVERSE VIEW OF SIX BOILERS OF THE COMMON STEAM ENGINE, NOW IN USE, representing them as exposed to the action of the fire, and unprotected by the water when the boat careens or leans to one side.

E is the central point of oscillation; AU the original line of level of the water in the boilers; and NV the level which the same water assumes when the boat careens six inches.

This drawing is intended to exemplify the unprotected situation of the boilers on one side, by which they become unduly heated at the parts marked V, and thereby cause a too rapid generation of steam in those boilers when the boat resumes her level. It also shows that there is, at the same time, a proportionate elevation of the water in the boilers on the opposite side, as at NA.

TT, &c. are the steam chambers. OO, &c. are the flues of the boilers. LL, an assumed river level. Water represented by horizontal lines. VV, &c. unprotected parts.

Six 14 inch flues, thus situated, will, if the boilers be 20 feet in length, expose to the direct action of the fire about 140 feet of surface, and the sides of the boilers about 30 feet more, making 170 feet, the weight of which would be about 1600 lbs. This, at a temperature of 1075°, or a heat which would appear red in the dark, would transform into steam more than 10 lbs. of water, or its equivalent, 1¼ gallons, which would be equal to 2125 gallons of steam at a temperate of 350°, or equal to a pressure of more than 120 lbs. to the superficial inch.

The drawing represents six boilers, three feet diameter, which are less than the common fronts for steamboats of the larger class; consequently the exposed surface herein shown is less than it would be in a larger furnace with the same angle of careen, to which they are daily, if not hourly, exposed, particularly in long voyages.

Fig. No. 2.

A SIDE VIEW OF THE CENTRE BOILER OF THE HYDROSTATIC ENGINE WHICH IS REPRESENTED IN FRONT IN No. 3.

This drawing represents a longitudinal section passed through the middle of the centre boiler and hydrostat.

The boiler is depressed one-half its diameter; for which reason, the back end of the boiler, and for some distance towards the furnace, is filled with water, as represented by the dotted line PT. The part marked VV, shows where the steam is first generated; ST, the pipe by which it passes first into the steam chest OL; I is the pipe by which it passes out again into the transversal supply pipe D, which charges the engine.

From this pipe D, is a communication with the hydrostat, or the governor of the quantity of water requisite for the supply of the boilers. This hydrostat is placed on the top of the central boiler, seen in fig. No. 3, where, from the circumstance of the boilers being full, the surplus water is supposed to be forced, by the superincumbent pressure of the steam upon the buoy A, down through the valve C, and up through the valve a, into the waste pipe which conveys it off at the point R. But the moment the pressure of the steam in the boilers

has wasted water enough to regain its equilibrium, and to allow the valve C, below the buoy A, to sink an inch, or less, the water passes through the opening of that valve into the boilers, without acting on the piston P; and so on, alternately.

P is the piston on which the steam rests at X with all its force, and on which the water only begins to exert an upward force when it becomes too high in the boilers for safety. When this is the case, the piston P, with its valve a, are lifted, and the surplus water escapes at R.

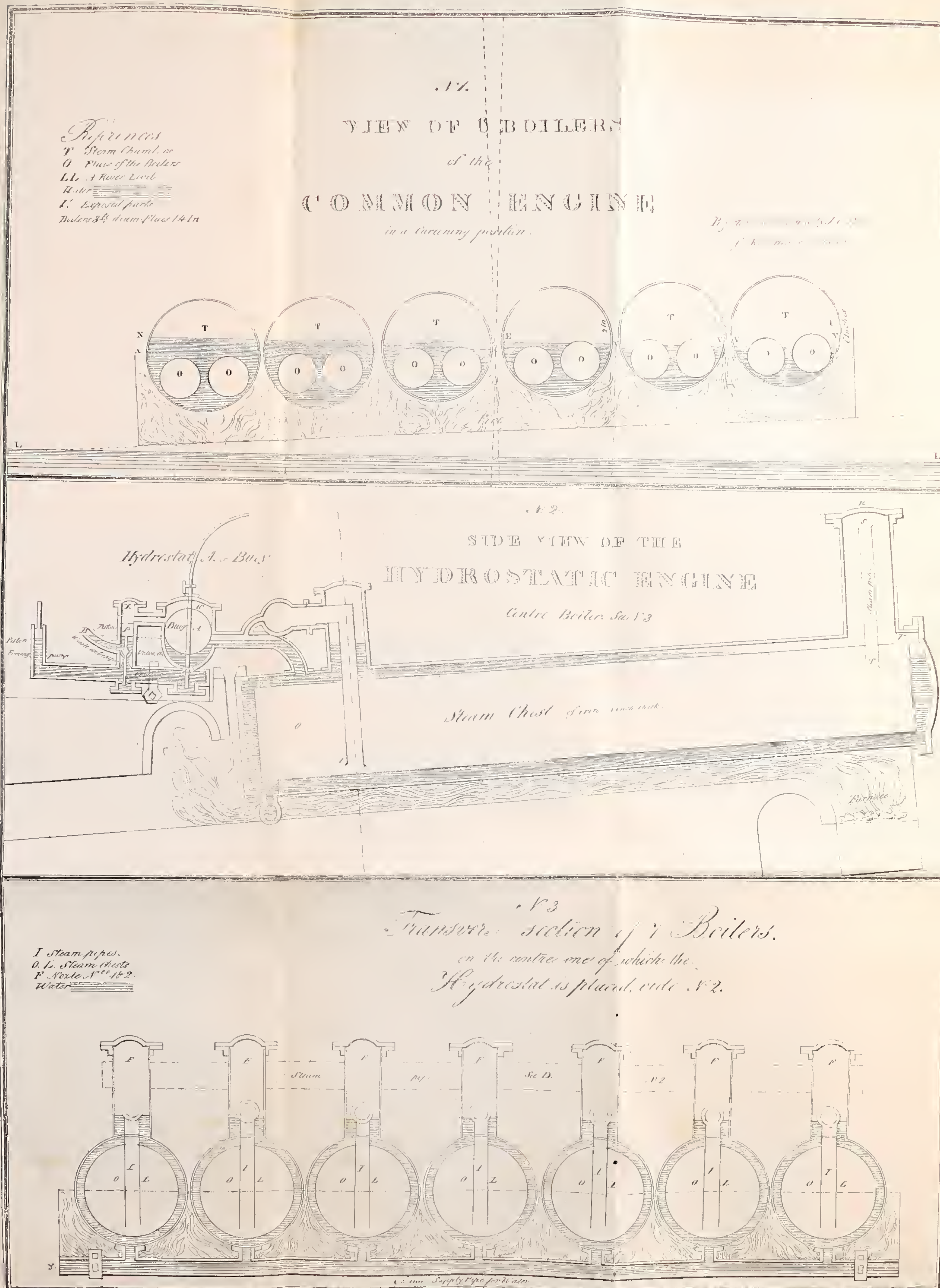
It is important to recollect that it is the *difference* of pressure on the top and bottom of the piston P that causes it to close after it is opened by the action of the water forced by the pump. Those that have been put in operation have been proportioned as follows: The lower valve, a, has been two inches in diameter, while the valve of the piston itself, P, was three inches. The square of three being nine, and the square of two being four, the difference of pressure will be as nine is to four; hence, the piston being acted upon by 900 lbs., and the valve, a, by only 400 lbs., the column of water is cut off by the pressure of the piston the moment the pump ceases to act on the water.

Fig. No. 3.

A TRANSVERSE SECTION OF SEVEN BOILERS, ON THE CENTRE ONE OF WHICH THE HYDROSTAT IS PLACED.

As the fire of the furnace never rises higher than the centre of the boilers, represented by the dotted line OL, OL, it is evident, if the boilers were three feet in diameter, that the boat would have to careen to one side three feet before the water could sink on the higher side of the boat, down to the fire line, if there *were* any place for the water to run to; but the back end of the boilers being full, the water could only run out of the pipes on the high side, and rise in the same ratio on the lower side; consequently, the water never could come down to the fire line.

By a reference to plate No. 2, it will be seen that the steam is taken into the steam chest at the high or furnace end of the boilers, which, being inclined half a diameter, force the steam to run along the top of the boilers VV, on the inside, as fast as it is generated, until it arrives at the nozzle R, in which is a steam pipe, ST, which conducts it into the steam chest OL. At the other end of the boiler will be seen another nozzle, F, in which the water and steam rise, and from which the steam is taken at D, for charging the engine. This arrangement is important, since, without it, the engine would draw over a portion of the water with the steam, and injure the working of the engine. These facts have been deduced from experience.


No. 1.
VIEW OF 6 BOILERS
of the
COMMON ENGINE
in a Careening position.
References
T Steam Chamber
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Water
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Centre Boiler. See No 3
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Transverse section of 7 Boilers.
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Hydrostat is placed, vide No 2.
I Steam pipes.
O. L. Steam chests
F Nozle Nos 1 & 2.
Water
Steam
pipe
Supply Pipe for Water

No. 37.

TABLE of the elastic force and the corresponding volumes of a same mass of atmospheric air, the temperature being supposed constant during each observation.

	Elasticity expressed in atmospheres of 0m,76 of mercury.	Elasticity expressed in centimetres of mercury.	Volume observed.	Volume calculated.	Temperature centigrade th.
1st series.	1.	80.09	479.73		14.3
	2.	156.9	244.687	244.88	14.3
	4.	326.706	117.168	117.6	14.4
	4.8	365.452	104.578	105.205	14.5
	6.5	504.072	75.976	76.222	Id.
	7.	557.176	68.910	69.007	Id.
	9.	688.54	55.45	55.801	Id.
	11.6	883.94	43.359	43.466	Id.
	12.	933.346	40.974	41.137	Id.
	14.	1070.862	35.767	35.881	Id.
2d series.	1.	79.497	481.806		13.3
	2.	156.112	244.986	245.205	13.5
	4.	313.686	121.542	121.989	13.6
	4.7	302.11	104.795	105.488	12.5
	5.	381.096	99.59	100.253	Id.
	6.1	464.752	81.787	82.218	12.6
	6.6	508.07	74.773	75.208	Id.
	6.6	506.592	74.985	75.427	Id.
	7.6	578.162	65.723	66.09	Id.
	7.6	580.002	65.473	65.881	Id.
	8.	637.108	59.767	60.039	13.8
	11.5	875.052	43.428	43.682	13.7
	11.6	881.202	43.146	43.378	Id.
	12.	962.108	39.679	39.758	14.5
	16.6	1269.132	30.136	30.140	13.7
3d series.	1.	76.	501.3		13.
	4.75	361.248	105.247	105.47	Id.
	4.94	375.718	101.216	101.412	Id.
	5.	381.228	99.692	99.946	13.
	6.	462.518	82.286	82.380	Id.
	6.58	500.078	76.095	76.193	Id.
	7.6	573.738	66.216	66.417	Id.
	11.3	859.624	44.308	44.325	Id.
	13.	999.236	37.851	38.132	Id.
	16.5	1262.000	30.119	30.192	Id.
	17.	1324.506	28.664	28.770	Id.
	19.	1466.736	25.885	25.978	Id.
	21.7	1653.49	22.968	23.044	Id.
	21.7	1658.44	22.879	22.972	Id.
	24.	1843.85	20.547	20.665	Id.
	26.5	2023.666	18.833	18.872	Id.
	27.	2049.868	18.525	18.588	Id.

Extract of report made to the Institute, at Paris, the 30th November, 1829, *by Baron de Prony, Arrago, Girard, Dulong, Repporter.*

No. 38.

	No. of the observations.	Small thermometer.	Large thermometer.	Elastic force in meters of mercury.	Elastic force in atmospheres of 0m,76.	Particular state of the observations.	Elastic force in meters of mercury at 0°.
1	29th Oct. 3d	122.97	123.7	1.62916	2.14	Maximum	1.62916
2	25th " 1st	132.58	132.82	2.1823	2.87	Ascending temp.	2.1767
3	28th " 1st	132.64	133.3	2.18726	2.88	Near max.	2.1816
4	28th " 2d	137.70	138.3	2.54456	3.384	Asc. temp.	2.5386
5	29th " 5th	149.54	149.7	3.484	4.584	Max.	3.4759
6	28th " 3d	151.87	151.9	3.69536	4.86	Asc. temp.	3.6868
7	25th " 2d	183.64	153.7	3.8905	5.12	Do.	3.881
8	2d Nov. 1st	163.00	163.4	4.9489	6.51	Max.	4.9383
9	30th Oct. 4th	168.40	168.5	5.61754	7.391	Do.	5.6054
10	28th " 4th	169.57	169.4	5.78624	7.613	Asc. temp. slow	5.7737
11	23d " 3d	171.88	172.34	6.167	8.114	Asc. temp.	6.151
12	28th " 5th	180.71	180.7	7.51874	9.893	Near max.	7.5001
13	25th " 4th	183.70	183.7	8.0562	10.6	Asc. temp.	8.0352
14	28th " 6th	186.80	187.1	8.72218	11.48	Asc. t. slow	8.6995
15	22d " 2d	188.30	188.5	8.8631	11.66	Max.	8.840
16	25th " 5th	193.70	193.7	10.0254	13.19	Asc. temp.	9.9989
17	28th " 7th	198.55	198.5	11.047	14.53	Asc. t. slow	11.019
18	25th " 6th	202.00	201.75	11.8929	15.63	Asc. temp.	11.862
19	24th " 1st	203.40	204.17	12.321	16.21	Asc. t. slow	12.2903
20	25th " 7th	206.17	206.10	13.0211	17.13	Asc. temp.	12.9872
21	2d Nov. 6th	206.40	206.8	13.0955	17.23	Maxim.	13.061
22	24th Oct. 2d	207.09	207.4	13.167	17.3	Near max.	13.1276
23	28th " 8th	208.45	208.9	13.7204	18.05	Asc. temp.	13.6843
24	25th " 8th	209.10	209.13	13.8049	18.16	Do.	13.769
25	25th " 9th	210.47	210.5	14.1001	18.55	Near max.	14.0634
26	28th " 9th	215.07	215.3	15.5407	20.44	Asc. temp.	15.4995
27	28th " 10th	217.23	217.5	16.1948	21.31	Do.	16.1528
28	28th " 11th	218.3	218.4	16.4226	21.6	Near max.	16.3816
29	30th " 8th	220.4	220.8	17.2248	22.66	Asc. temp.	17.1826
30	30th " 1st	223.88	224.15	18.2343	23.994	Maxim.	18.1894

The preceding table contains the thirty observations made under the most favorable circumstances.

No. 39.

TABLE of the expansive force of the vapor of water or steam, when enclosed in a close vessel, and relieved from the pressure of the atmosphere; taken at every 10° of temperature, from 10° to 212.°

Temperature in degrees of Fahr. therm.	Pressure of the vapor, or the force which it will exert to enter into a vacuous space.			Pressure of the atmosphere, or the force which it will exert to enter into a space filled with the vapor. Barometer at 30 inches.		
	Column of mercury.	Column of water.	Pressure per sq. inch.	Column of mercury.	Column of water.	Pressure per square inch.
	Inches.	Ft. in.	Lbs. oz.	Inches.	Ft. in.	Lbs. oz.
40 below zero.	.01	0 .17	0 .1	29.987	33.10.63	14 10.5
30 below zero.	.02	0 .27	0 .15	29.98	33 10.53	14 10.45
20 below zero.	.03	0 .4	0 .23	29.97	33 10.4	14 10.37
10 below zero.	.043	0 .58	0 .33	29.957	33 10.22	14 10.27
0	.064	0 .87	0 .5	29.936	33 9.93	14 10.1
10	.09	0 1.22	0 .7	29.91	33 9.58	14 9.9
20	.129	0 1.75	0 1.	29.871	33 9.0	14 9.6
30	.186	0 2.5	0 1.44	29.814	33 8.3	14 9.16
32 (freezing)	.2	0 2.7	0 1.56	29.8	33 8.1	14 8.04
40	.263	0 3.5	0 2.	29.737	33 7.3	14 8.6
50	.375	0 5.1	0 2.9	29.625	33 5.7	14 7.70
60	.524	0 7.1	0 4.1	29.476	33 3.7	14 6.5
70	.721	0 9.8	0 5.6	29.279	33 1.	14 5.
80	1.	1 1.56	0 7.83	29.	32 9.24	14 2.77
90	1.36	1 6.5	0 10.4	28.64	32 3.25	14 0.2
100	1.86	2 1.25	0 14.4	28.14	31 9.5	13 12.2
110	2.53	2 10.25	1 3.6	28.47	31 0.5	13 7.
120	3.33	3 9.	1 10.	27.67	30 1.	13 0.6
130	4.34	4 10.75	2 1.5	25.66	29 0.	12 9.1
140	5.74	6 6.	2 13.	24.26	27 4.	11 13.6
150	7.42	8 4.5	3 9.8	22.58	25 6.25	11 0.8
160	9.46	10 8.	4 9.9	20.54	23 2.	10 0.7
170	12.13	13 8.5	5 14.7	17.87	20 2.25	8 11.19
180	15.15	17 1.5	7 6.4	14.85	16 9.25	7 4.2
190	19.00	21 3.5	9 3.3	11.	12 7.25	5 7.3
200	23.64	26 8.5	11 8.9	6.36	7 2.25	3 1.7
210	28.84	32 7.	14 1.9	1.16	1 3.	0 8.7
212 (boiling)	30.	33 10.75	14 10.6	The vapor	and the atmos	phere equal.

No. 40.

TABLE of the expansive force of Steam, when enclosed in a close vessel taken at every 5° of temperature, from 212° of Fahrenheit, or boiling up to 325°.

Temperature in degrees of Fahr. therm.	Pressure of the steam, or the force which it will exert to enter into a vacuous space.			Pressure of the steam against the atmosphere, when the barometer is at 30 inches, or the force which it will exert to escape from the close vessel into the open air.		
	Column of mercury.	Column of water.	Pressure per sq. inch.	Column of mercury.	Column of water.	Pressure per square inch.
	Inches.	Ft. in.	Lbs. oz.	Inches.	Ft. in.	Lbs. oz.
212 (boiling)	30.	33 10.75	14 10.6	The steam	equal to the	atmosphere.
215	31.83	35 11	15 9	1.83	2 0	0 15
220	34.99	39 6	17 1	4.99	5 7	2 7
225	38.20	43 2	18 10	8.20	9 4	4 0
230	41.75	47 2	20 7	11.75	13 4	5 13
235	45.58	51 6	22 5	15.58	17 8	7 11
240	49.67	56 1	24 4	19.67	22 3	9 10
245	53.88	60 10	26 4	23.88	27 0	11 10
250	58.21	65 9	28 8	28.21	31 11	13 14
255	62.85	71 0	30 12	32.85	37 2	16 2
260	67.73	76 6	33 2	37.73	42 8	18 8
265	72.76	82 2	35 9	42.76	48 4	20 15
270	77.85	87 11	38 1	47.85	54 1	23 7
275	83.13	93 11	40 11	53.13	60 1	26 1
280	88.75	100 3	43 7	58.75	66 5	28 13
285	94.35	106 7	46 3	64.35	72 9	31 9
290	100.12	113 1	49 0	70.12	79 3	34 6
295	105.97	119 8	51 4	75.97	85 10	36 10
300	111.81	126 4	54 12	81.81	92 6	40 2
305	117.68	132 11	57 9	87.68	99 1	42 15
310	123.53	139 6	60 8	93.53	105 8	45 14
315	129.29	146 1	64 0	99.29	112 3	49 6
320	135.	152 6	66 1	105.00	116 5	51 7
325	140.70	158 11	68 14	110.70	125 1	54 4

No. 41.

Of the Properties of the steam of water of different degrees of elastic force.

Total force of steam.			Excess of force above the atmosphere.		Temperature Fahren.	Volume in cubic feet, the water being 1.	Weight of a cubic foot in grains.	Specific gravity, air being 1.	Velocity into a vacuum, in feet per second.	Heat of conversion from water of 52° to steam in degrees.
In atmospheres.	In inches of mercury.	In pounds per circular inch.	In pounds per circular inch.	In pounds per square inch.						
.0183	.55	.21	—11.33	—14.4	60	721.90	6.1	.0115	1377	1008
.0333	1.	.385	—11.155	—14.2	77	410.10	10.7	.0202	1400	1025
.0667	2.	.77	—10.77	—13.7	98.7	214.00	20.5	.0388	1427	1047
.1	3.	1.15	—10.39	—13.2	112.5	145.70	30	.0568	1445	1061
.133	4.	1.54	—10.0	—12.7	123.	111.30	39	.0744	1458	1071
.25	7.5	2.88	— 8.66	—10.99	147.6	61.87	71	.134	1499	1096
.5	15	5.77	— 5.77	— 7.33	178.	32.49	135	.255	1526	1126
.75	22.5	8.65	— 2.89	— 3.66	197.4	22.32	196	.371	1549	1146
1.00	30	11.54	0.	— 0.	212	17.11	254.7	.484	1566	1160
1.17	35	13.46	1.92	2.44	220	14.97	292	.553	1575	1168
1.5	45	17.31	5.77	7.33	233.8	11.78	363	.687	1591	1182
1.75	52.5	20.19	8.65	10.99	242.5	10.22	427	.81	1601	1191
2.00	60	23.08	11.54	14.65	250.2	9.05	483	.915	1610	1199
2.5	75	28.85	17.31	21.98	263.5	7.37	593	1.123	1625	1212
3.0	90	34.62	23.08	29.3	274.7	6.23	700	1.33	1638	1223
3.5	105	40.39	28.85	36.63	284.5	5.42	810	1.53	1649	1233
4	120	46.16	34.62	43.95	293.1	4.79	910	1.728	1658	1241
5	150	57.7	46.15	58.60	308	3.91	1110	2.12	1674	1256
6	180	69.24	57.7	73.25	320.6	3.31	1317	2.5	1688	1269
7	210	80.78	69.24	87.90	331.5	2.88	1520	2.88	1700	1280
8	240	92.32	80.78	102.55	341.2	2.55	1660	3.25	1710	1289
9	270	103.86	92.32	117.20	350	2.29	1910	3.61	1720	1298
10	300	115.4	103.86	131.85	358	2.09	2100	3.97	1729	1306
20	600	230.8	219.26	278.35	414	1.11	3940	7.44	1786	1362
30	900	346.2	334.66	424.85	450	.77	5670	10.75	1823	1398
40	1200	461.6	450.06	571.35	477	.60	7350	13.88	1850	1425

No. 42.

Of the proportions of single acting Steam Engines, equivalent to different numbers of horses; the horse power being 33,000 pounds raised one foot high per minute, and the elastic force of the steam in the boiler = 35 inches of mercury.

STEAM ACTING EXPANSIVELY.								Steam at full pressure throughout the stroke in the same engine.	
No. of horse power.	Diameter of the steam piston in inches.	Mean pressure on the piston in pounds, at 5½ lbs. per circular inch.	Velocity of the steam piston in feet per minute.	Length of the stroke in feet.	Number of strokes per minute.	Water required per hour to supply the boiler.	Coals consumed per hour, in pounds.	Number of horses' power.	Coals consumed per hour, in pounds.
	Inches.		Feet.	Feet.		Cub. feet.	Lbs.		Lbs.
10	26.4	3850	174	4.4	19¾	11.1	114	11.2	152
15	31.1	5324	187	5.2	18	16.7	164	16.8	220
20	34.9	6702	197	5.8	17	22.3	213	22.5	285
25	38.1	8012	203	6.3	16	27.7	257	28	343
30	41.1	9270	214	6.8	15¾	33.3	307	33.5	410
35	43.7	10490	221	7.3	15¼	39	356	39.2	475
40	46.1	11670	227	7.7	14¾	44.5	401	45	536
45	48.3	12820	232	8.0	14½	50	450	50.5	600
50	50.4	13950	237	8.4	14½	55.5	500	56	670
55	52.3	15050	242	8.7	14	61.2	551	62	735
60	54.2	16140	246	9.0	13¾	66.7	600	67	800
65	56.0	17210	250	9.3	13½	72.1	649	73	865
70	57.6	18260	254	9.6	13¼	78	702	78	940
75	59.2	19290	257	9.8	13	83.3	750	84	1000
80	60.8	20310	260	10.1	13	89	801	89	1070
85	62.3	21330	264	10.4	12¾	945.5	851	95	1140
90	63.7	22320	267	10.6	12½	100	900	101	1200
100	66.5	24290	272	11.0	12¼	111	999	112	1330
120	71.5	28100	283	11.9	12	133	1197	134	1600
140	76.0	31790	291	12.6	11½	156	1404	157	1860
160	80.2	35380	299	13.3	11¼	178	1602	179	2140
180	84.1	38870	307	14.0	11	200	1800	201	2400
200	87.7	42300	313	14.6	10¾	222	1998	224	2650
213½	90	44550	318	15.0	10½	237	2133	265	2860

No. 43.

Of the proportions of double acting Steam Engines, equiva lent to different numbers of horses; the horse power being 33,000 pounds raised one foot high per minute, and the elastic force of the steam in the boiler = 35 inches of mercury.

STEAM ACTING EXPANSIVELY.								Steam acting at full pressure throughout the stroke in the same engine.	
No. of horses' power.	Diameter of the steam piston in inches.	Mean pressure on the piston in pounds, at 4.8 pounds per circular inch.	Velocity of the steam piston in feet per minute.	Length of the stroke in feet.	Number of strokes per minute.	Water required per hour to supply the boiler.	Coals consumed per hour, in pounds.	Number of horses' power.	Coals consumed per hour, in pounds.
	Inches.	Lbs.	Feet.	Feet.		Cub. feet.	Lbs.		Lbs.
1	7.8	289	114	1.3	44	.8	15	1.46	31.5
2	10.25	516	131	1.75	37½	1.57	23	2.95	48
3	12.05	697	141	2	35	2.36	30½	4.4	64
4	13.52	877	149	2.25	33	3.13	38	5.9	80
5	14.9	1049	157	2.5	31½	3.92	45	7.4	94
6	15.9	1214	162	2.65	30½	4.7	53	8.85	111
7	16.9	1373	167	2.8	29¾	5.5	60	10.3	126
8	17.85	1527	171	2.97	29	6.3	67	11.8	140
9	18.7	1678	175	3.1	28¼	7.05	73	13.3	153
10	19.5	1826	180	3.25	26¾	7.42	80	14.6	168
12	20.9	2113	186	3.5	26½	9.4	95	17.7	199
14	22.3	2390	191	3.7	25¾	11.0	108	20.7	230
16	23.6	2659	196	3.9	25	12.6	122	23.6	256
18	24.7	2922	201	4.1	24½	14.1	135	26.5	283
20	25.75	3179	206	4.3	24	15.7	149	29.5	312
22	26.75	3431	211	4.5	23½	17.3	163	32.5	341
24	27.7	3678	213	4.6	23¼	18.8	176	35.5	370
26	28.6	3922	216	4.75	22¾	20.4	189	38.4	395
28	29.45	4161	220	4.9	22½	22.	203	41.3	425
30	30.27	4397	222	5.04	22¼	23.5	216	44.2	451
32	31.1	4630	226	5.2	21¾	25.1	230	47.3	480
34	31.82	4860	229	5.3	21½	26.7	243	50	510
36	32.52	5088	232	5.43	21¼	28.3	256	53	535
38	33.3	5313	234	5.55	21	29.7	269	56	561
40	34	5535	237	5.67	21	31.4	283	59	596
42	34.63	5756	239	5.77	20¾	33.0	297	62	624
44	35.13	5919	241	5.85	20½	34.5	311	65	652
46	35.9	6190	244	6.0	20½	36.2	324	67.5	680
48	36.5	6404	246	6.1	20¼	37.7	338	70.5	709
50	37.13	6617	248	6.2	20	39.3	353	73.5	739
52	37.7	6828	250	6.3	20	40.7	367	76.4	768
54	38.3	7036	252	6.4	19¾	42.4	381	79.3	798
56	38.85	7245	254	6.49	19½	44.0	396	82.2	827

TABLE 43—Continued.

STEAM ACTING EXPANSIVELY.								Steam acting at full pressure throughout the stroke in the same engine.	
No. of horses' power.	Diameter of the steam piston in inches.	Mean pressure on the piston in pounds, at 4.8 pounds per circular inch.	Velocity of the steam piston in feet per minute.	Length of the stroke in feet.	Number of strokes per minute.	Water required per hour to supply the boiler.	Coals consumed per hour.	Number of horses' power.	Coals consumed per hour, in pounds.
	Inches.	Lbs.	Feet.	Feet.		Cub. feet.	Lbs.		Lbs.
58	39.4	7.453	255	6.57	19½	45.4	409	85.1	850
60	39.9	7.656	257	6.65	19½	47.0	423	88.1	887
62	40.5	7.860	259	6.75	19¼	48.6	437	91.0	[illegible]
64	41.0	8.062	260	6.83	19	50.2	452	93.9	[illegible]
66	41.5	8.263	261	6.9	19	51.8	466	96.8	975
68	42.0	8.462	263	7	18¾	53.4	481	99.7	1005
70	42.5	8.662	265	7.1	18¾	55.0	495	102.7	1035
72	43.0	8.858	266	7.17	18½	56.6	509	105.6	1064
74	43.4	9.043	268	7.23	18½	58.1	514	108.5	1094
76	43.9	9.250	269	7.3	18½	59.8	538	111.4	1123
78	44.4	9.444	270	7.4	18¼	61.5	554	114.3	1153
80	44.8	9.637	272	7.47	18¼	62.5	563	117.3	1182
85	45.9	10.120	275	7.65	18	66.5	599	124.6	1256
90	46.97	10.590	279	7.83	17¾	70.5	635	131.9	1330
95	48.0	11.060	282	8.0	17¾	74.4	670	139.2	1404
100	49.0	11.520	284	8.16	17½	78.2	704	146	1478
105	49.95	11.980	287	8.32	17¼	82.1	739	153.3	1552
110	50.9	12.430	290	8.5	17	86.0	774	161.6	1626
115	51.6	12.760	292	8.6	17	89.9	809	167.9	1700
120	52.7	13.330	294	8.8	16¾	93.8	844	175.2	1774
125	53.6	13.760	297	8.9	16¾	97.7	879	182.5	1848
130	54.4	14.210	299	9.0	16½	101.7	915	1[illegible]9.8	1921
135	55.3	14.740	300	9.2	16¼	105.6	950	197.1	1995
140	56.1	15.080	302	9.35	16¼	109.5	986	204.4	2069
145	56.84	15.510	306	9.47	16¼	113.4	1021	211.7	2143
150	57.6	15.930	308	9.6	16	117.3	1055	219.0	2217
155	58.4	16.360	310	9.7	16	121.2	1091	226.3	2291
160	59.1	16.780	312	9.83	15¾	125.2	1127	233.6	2364
175	61.3	18.030	318	10.2	15½	129.1	1162	240.9	2438
180	62.0	18.440	320	10.3	15½	133.0	1197	248.4	2512
200	67.7	22.000	334	11.3	14¾	156.4	1408	292	2956